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THE MINERALOGICAL SOCIETY

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EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, January 26, 1915, *at* 5 *p.m.*

Dr. A. E. H. Tutton, M.A., F.R.S., President, in the Chair.

Messrs. J. P. De Castro and G. F. Herbert Smith were elected Auditors of the Accounts for the year ending December 31, 1914.

GENERAL MEETING.

Held in the Apartments of the Geological Society, January 26, 1915, *at* 5.30 *p.m.*

Dr. A. E. H. Tutton, M.A., F.R.S., President, in the Chair.

Twenty-one Members and three Visitors were present.

The following papers were read :—

1. On the dispersion of the Felspars : by Mr. S. Kôzu.

2. Note on the colour of some alluvial Diamonds, and of Pyrrhotite : by Mr. F. P. Mennell (pp. 202, 205).

3. On crystals of Calomel from Spain : by Prof. G. Cesàro.

4. General formula for the birefringence of a crystal-plate in terms of the angles which its normal makes with the optical principal axes : by Prof. G. Cesàro (p. 163).

5. On a numerical relation of the sum of the symmetry-axes situated in the symmetry-planes of a polyhedron : by Prof. G. Cesàro (p. 173).

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, March 16, 1915, *at* 5 *p.m.*

Dr. A. E. H. Tutton, M.A., F.R.S., President, in the Chair.

Dr. Lewis Leigh Fermor was provisionally elected an Ordinary Member of the Society.

The deaths of Professor James Geikie and Mr. F. W. Rudler and the resignation of Mr. H. Dewey were announced.

The audited Balance-sheet for the year ending December 31, 1914,

was approved, and the Secretary was instructed to insert it in the Minutes and to publish it in the next number of the Journal.

The Editor was instructed, under the special circumstances, to publish Prof. Cesàro's papers in the original French.

GENERAL MEETING.

Held in the Apartments of the Geological Society, March 16, 1915, *at* 5.30 *p.m.*

Dr. A. E. H. Tutton, M.A., F.R.S., President, in the Chair.

Sixteen Members and two Visitors were present.

The election of Dr. L. L. Fermor as an Ordinary Member of the Society was confirmed.

The following papers were read :—

1. The dispersion of Adularia from St. Gotthard, Orthoclase from Madagascar, and Moonstone from Ceylon : by Mr. S. Kôzu.

2. Orpiment from Balia : by Prof. G. Cesàro.

3. Stereographic projection of a cone touching the sphere of projection along a small circle : by Prof. G. Cesàro.

4. The meteoric stone of Launton, Oxfordshire : by Dr. G. T. Prior.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, June 15, 1915, *at* 5 *p.m.*

Dr. A. E. H. Tutton, M.A., F.R.S., President, in the Chair.

Professor Arthur Leonard Parsons was provisionally elected an Ordinary Member of the Society.

The deaths of Sir Arthur H. Church and Dr. Hugo Müller, Past-presidents, of Professor G. Strüver, Honorary Member, and of Mr. J. J. Beringer, Ordinary Member, were announced. The Secretary was instructed to send letters of condolence from the Council and Members of the Society to Lady Church and Mrs. Müller. The action of the President in sending a letter of condolence to Mrs. Beringer was approved.

The following changes in the list of Officers and Council were approved

for recommendation to the Members of the Society :—President: Mr. Barlow in place of Dr. Tutton; Ordinary Members of Council: Messrs. Barker, Barrow, Cullis, and Mennell, in place of the four retiring Members of Council (Messrs. Butler, De Castro, Kitto, and Liversidge).

Letters from the International Commission for the publication of the 'Tables Annuelles de Constantes' were further considered, and it was resolved to contribute £5 towards the expenses of publishing the next special part referring to Mineralogy.

A proposal for exchange of publications with the Department of Mines, Melbourne, was accepted.

GENERAL MEETING.

Held in the Apartments of the Geological Society, June 15, 1915, *at* 5.30 *p.m.*

Dr. A. E. H. Tutton, M.A., F.R.S., President, in the Chair.

Twenty Members and five Visitors were present.

The election of Prof. A. L. Parsons as an Ordinary Member of the Society was confirmed.

The following papers were read :—

1. Detrital Andalusite in Cretaceous and Eocene sands: by Mr. G. M. Davies (p. 218).

2. The Garnets and streaky rocks of the English Lake District: by J. F. N. Green (p. 207).

3. On Autunite: by A. F. Hallimond (p. 221).

4. On the errors in the angle of the optic axes resulting from those of the principal refractive indices determined by total reflection: by Mr. S. Kôzu.

5. Influence of temperature on the optic axial angle of Sanidine: by Mr. S. Kôzu.

6. The meteoric stones of Warbreccan, Queensland: by Dr. G. T. Prior.

7. Proustite from Cobalt, Ontario: by Prof. A. L. Parsons.

MINERALOGICAL SOCIETY.

ABSTRACT OF RECEIPTS AND PAYMENTS FROM JANUARY 1 TO DECEMBER 31, 1914.

Receipts.	£ s. d.	£ s. d.
Balance from 1913—		
Bank	51 3 5	
Office	4 4	
		51 7 9
Subscriptions—(1) current	48 5 0	
(2) arrears	8 4 0	
(3) advance	1 1 0	
		57 10 0
Entrance fees		6 6 0
Sale of publications—		
By Publishers	55 16 7	
By G. Savigar	10 10	
		56 7 5
Dividends on Investments		25 11 11
Hon. Secretary for Illustrations		1 6 0
		£198 9 1

Payments.	£ s. d.	£ s. d.
Printing Magazine (No. 78)	21 13 2	
Authors' copies	3 15 6	
Illustrations	7 8 3	
		32 16 11
Printing Magazine (No. 79)	22 1 6	
Authors' copies	3 15 0	
Illustrations	1 4 6	
		27 1 0
Miscellaneous Printing—		
Williams & Strahan	5 2 8	
Oxford Press (List of Members, etc.)	1 7 6	
		6 10 2
Editor's Honorarium (1913)		10 10 0
G. Savigar for care of stock of Publications (1913)		1 1 0
Porter's Fee at meetings		1 0 0
Fee for manipulating lantern		10 0
Donation to 'Tables Annuelles de Constantes'		5 0 0
Postage and Parcels—		
Magazine	5 2 0	
G. Savigar (1913)	14 6	
Hon. Secretary (1913)	6 0	
Hon. Treasurer (1913)	7 7	
		6 10 1
Investments—		
Dividends	25 4 5	
Broker's fee on above	7 6	
		25 11 11
Bank Charges		2 0
„ New Cheque-book		4 2
Balance at Bank	81 7 9	
„ in Office	4 1	
		81 11 10
		£198 9 1

BALANCE SHEET.

DECEMBER 31, 1914.

LIABILITIES.	£	s.	d.
Owing for Editor's Honorarium (1914)	10	10	0
,, G. Savigar for care of stock of Publications (1914)	1	1	0
,, Do. for postage (1914)		7	11
,, Hon. Secretary for postage (1914)		3	11
,, Hon. Treasurer for postage (1914)		9	4
,, fee for manipulating lantern (1914)		10	0
Excess of assets over liabilities	878	5	8
	£891	7	10

ASSETS.	£	s.	d.	£	s.	d.
Balance at Bank	81	7	9			
,, in Office		4	1			
				81	11	10
Consols (£1112 15*s.* 4*d.*, valued at £68)				756	13	2
Sale of Publications (1914)—						
Owing from Publishers	32	14	10			
,, G. Savigar		8	0			
				33	2	10
Arrears of Subscriptions valued at				20	0	0
				£891	7	10

The stock of Publications and the value of the Library are not included in the above assets. (*Signed*) W. P. BEALE,
Hon. Treasurer.
Feby. 1915.

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THE MINERALOGICAL MAGAZINE

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THE MINERALOGICAL SOCIETY.

No. 81. SEPTEMBER, 1915. Vol. XVII.

Formule générale donnant la biréfringence d'une lame cristalline en fonction des angles que sa normale fait avec les axes d'élasticité optique. La formule approximative habituelle s'obtient en y supposant les indices infinis, tout en conservant entre eux les différences finies qui existent en réalité.

Par G. Cesàro.

Président de l'Académie royale de Belgique, Professeur de Cristallographie et Minéralogie à l'Université de Liége.

[Read January 26, 1915.]

DANS les questions relatives aux biréfringences on emploie des formules approximatives, et je ne trouve relatée nulle part la formule donnant exactement la biréfringence d'une face en fonction des angles que sa normale fait avec les axes d'élasticité optique. Le but de cette note est d'indiquer cette formule, d'ailleurs très simple, et surtout de montrer que la formule approximative habituelle se déduit de la formule exacte en y supposant l'indice moyen infini.

On s'explique alors pourquoi, dans la plupart des questions relatives aux biréfringences, la grandeur réelle des indices importe peu : pourvu que l'indice moyen conserve les différences existant en réalité avec les

indices extrêmes, sa valeur peut subir d'amples variations sans que le résultat varie d'une façon appréciable.[1]

Voici la propriété : *' Si l'on considère un ellipsoïde qui va en croissant, tout en conservant entre ses axes des différences finies constantes, la différence des axes de l'ellipse de section faite par un plan diamétral de direction constante tend vers une limite finie lorsque les axes de l'ellipsoïde augmentent au delà de toute limite.*

' Pendant le mouvement de croissance, les normales aux sections cycliques vont en s'approchant du grand axe de l'ellipsoïde, mais tendent vers une position limite lorsque les axes de l'ellipsoïde tendent vers l'infini.

' Si n_g, n_m, n_p *sont les axes de l'ellipsoïde, et*

$$n_g - n_m = A$$
$$n_g - n_p = B$$
$$n_m - n_p = C$$

leurs différences constantes, la position limite de la normale à une section cyclique fait avec le grand axe de l'ellipsoïde un angle V *donné par*

$$\operatorname{tg}^2 V = \frac{C}{A} \cdot \qquad (1)$$

' Pendant le mouvement, les normales aux sections cycliques font des angles variables avec la normale fixe de la section diamétrale considérée ; si l'on désigne par θ *et* θ' *les valeurs limites de ces angles, c'est-à-dire les angles que la normale fixe fait avec les droites définies par* (1), *la différence entre les axes de la section diamétrale a pour limite*

$$X = B \sin\theta \sin\theta'.'$$

Optiquement, l'ellipsoïde est l'ellipsoïde inverse, ses axes n_g, n_m, n_p les indices principaux, leurs différences A, B, C les biréfringences principales, les normales aux sections cycliques les axes optiques, les axes d'une section diamétrale sont les indices relatifs à une direction de propagation normale à la lame, et la différence X entre ces axes est la différence entre ces indices, c'est-à-dire la biréfringence de la lame. Voici la démonstration de la propriété.

Marche des axes optiques[2] *pendant le mouvement de croissance de l'ellipsoïde.*

[1] Voir, par exemple : Bull. de l'Acad. royale de Belgique (Classe des Sciences), No. 7, Juillet 1908, p. 649, et aussi l'exemple de la biréfringence de la *calcite* déduite de la biréfringence de son clivage, traité à la fin de la présente note.

[2] J'emploie le langage optique ou le langage géométrique suivant que l'un ou l'autre est plus concis ou plus clair.

Si V est l'angle *variable* que fait la normale à une section cyclique avec le grand axe de l'ellipsoïde, on a

$$\operatorname{tg} V = \frac{n_g}{n_p}\sqrt{\frac{n_m^2 - n_p^2}{n_g^2 - n_m^2}}, \qquad (2)$$

ou, en désignant par x l'indice moyen n_m,

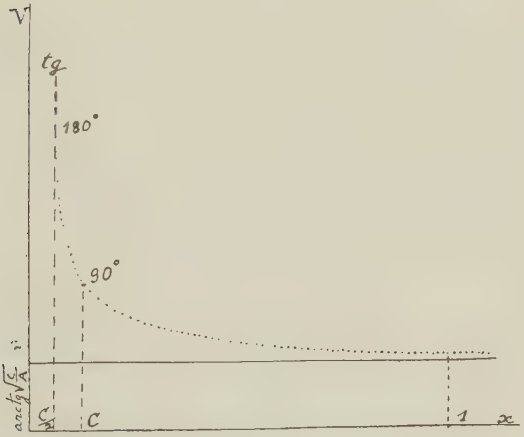
$$V = \operatorname{arctg}\left\{\sqrt{\frac{C}{A}}\cdot\frac{x+A}{x-C}\cdot\sqrt{\frac{2x-C}{2x+A}}\right\}.$$

La dérivée

$$V' = -\sqrt{AC}\cdot\frac{3x+A-C}{x(2x+A-C)\sqrt{(2x+A)(2x-C)}}$$

est essentiellement négative, car A et C sont de l'ordre des millièmes et x est plus grand que l'unité[1]; donc V décroît constamment lorsque x augmente, et la normale à la section cyclique va en se rapprochant, d'une manière continue, du grand axe de l'ellipsoïde. Pour $x = \infty$,

$$V = \operatorname{arctg}\sqrt{\frac{C}{A}}.$$



La figure représente schématiquement la variation de V avec l'indice moyen. Dans la partie optiquement utile, la branche devient presque

[1] Cette restriction est même inutile, car, vu que $n_g > n_m > n_p$, A et C sont des nombres positifs; or, pour que V soit réel, il faut que $2x > C$; on a donc aussi $3x > C$, etc.

parallèle à l'axe des x ; ainsi, par exemple, pour le *péridot* pour lequel

$$n_g = 1{,}697 \qquad n_m = 1{,}678 \qquad n_p = 1{,}661 \text{ (Des Cloizeaux)}$$

et, par conséquent,

$$A = 19 \text{ millièmes}, \qquad C = 17 \text{ millièmes},$$

on a

x	1,017[1]	1,6	1,678	1,7	10	∞
V	44° 10′	43° 53′,5	43° 52′	43° 51′,5	43° 29′	43° 24′ 27″,5[2]

Différence des axes d'une ellipse diamétrale découpée par un plan dont la normale fait avec les axes de l'ellipsoïde des angles α, β, γ ($u = \cos\alpha$, $v = \cos\beta$, $w = \cos\gamma$). — On suppose l'axe x dirigé suivant n_p, y suivant n_m, z suivant n_g. —

Si sur le diamètre normal à chaque section diamétrale on porte des longueurs égales aux inverses $\frac{1}{n}$ des axes de la section, le lieu des extrémités est une surface à deux nappes,[3] ayant pour équation polaire

$$\frac{u^2 n_p^2}{n^2 - n_p^2} + \frac{v^2 n_m^2}{n^2 - n_m^2} + \frac{w^2 n_g^2}{n^2 - n_g^2} = 0,$$

ou

$$(u^2 n_p^2 + v^2 n_m^2 + w^2 n_g^2)\, n^4 \qquad (3)$$
$$- (n_g^2 n_m^2 \sin^2\alpha + n_g^2 n_p^2 \sin^2\beta + n_p^2 n_m^2 \sin^2\gamma)\, n^2 + n_p^2 n_m^2 n_g^2 = 0$$

et, pour abréger,

$$Mn^4 - Nn^2 + P = 0.$$

La résolution de cette équation donnerait les valeurs n' et n'' des axes de l'ellipse de section,[4] indices de réfraction du rayon normal à la section considérée, axes dont la différence est la biréfringence de la section

$$X = n' - n''.$$

On a

$$X^2 = n'^2 + n''^2 - 2n'n'' = \frac{N}{M} - 2\sqrt{\frac{P}{M}} = \frac{N - 2\sqrt{MP}}{M}, \qquad (4)$$

[1] C'est la plus petite valeur que l'on puisse attribuer à x, car elle correspond à $n_p = 1$.

[2] On voit que lorsque x varie depuis 1,017 jusqu'à ∞, V ne varie que d'environ 0° 46′ ; on peut donc donner à l'indice moyen, dans la formule (2), des valeurs grossièrement approchées, telles que 1,6 et 1,7, pour obtenir V à une minute près.

[3] Appelée *surface des vitesses normales*, le rayon vecteur, inverse de l'indice, représentant la vitesse de propagation normale.

[4] J'ai donné une solution géométrique de ce problème dans les Mémoires de la Société royale des Sciences de Liége, 1898, 2e série, t. xx, pp. 6 et 7.

et, en remplaçant M, N, P par leurs valeurs, $X^2 =$

$$\frac{n^2_m \sin^2\alpha + n^2_q n^2_p \sin^2\beta + n^2_m n^2_p \sin^2\gamma - 2n_q n_m n_p \sqrt{n^2_p \cos^2\alpha + n^2_m \cos^2\beta + n^2_q \cos^2\gamma}}{n^2_p \cos^2\alpha + n^2_m \cos^2\beta + n^2_q \cos^2\gamma} \qquad (5)$$

Telle est la formule donnant exactement, de la façon la plus générale, la biréfringence d'une face en fonction des indices principaux et des angles que la normale à la face fait avec les axes d'élasticité optique.

On vérifie facilement cette formule dans les cas particuliers : section normale à un axe d'élasticité, ou passant par un axe d'élasticité optique; en égalant le numérateur à zéro, on retombe, après calculs, sur la normale à une section cyclique, etc.

Limite vers laquelle tend X lorsque l'indice moyen tend vers l'infini, en laissant les biréfringences constantes. —

Si l'on désigne l'indice moyen par x, on a

$$n_g = x + A$$
$$n_m = x$$
$$n_p = x - C;$$

lorsque x tend vers ∞,

$$\lim. \frac{n_g}{x} = \lim. \frac{n_p}{x} = 1,$$

de sorte que, si l'on prend x pour l'infiniment grand principal, n_g et n_p sont des infinis du premier ordre. Quant aux coefficients

$$M = \Sigma n^2_p \cos^2 a, \quad N = \Sigma n^2_g n^2_m \sin^2 a, \quad P = n^2_g n^2_m n^2_p,$$

ils sont respectivement de l'ordre *deux*, *quatre* et *six*, vu que

$$\lim. \frac{M}{x^2} = 1, \quad \lim. \frac{N}{x^4} = 2, \quad \lim. \frac{P}{x^6} = 1.$$

Il s'ensuit que les formules (5) et (4) deviennent indéterminées lorsqu'on y fait $n_m = \infty$, car le dénominateur est un infini du second ordre et le numérateur est la différence de deux infinis du quatrième ordre, différence qui pourrait être du quatrième ordre,[1] mais qui est ici d'un ordre inférieur, vu que son rapport à x^4 tend vers zéro; suivant l'ordre de cette différence, X^2 augmentera indéfiniment avec x, tendra vers une quantité finie positive, ou vers zéro.[2] Pour faire disparaître l'indétermination, on écrit

$$X^2 = \frac{N^2 - 4MP}{M(N + 2\sqrt{MP})}, \qquad (6)$$

[1] Dans ce cas, X augmenterait indéfiniment avec x.

[2] On ne réussit pas mieux en divisant les deux termes de l'expression (5) par n^4_m : l'indétermination apparaît alors sous la forme $\frac{0}{0}$.

puis

$$N^2-4MP=\{(n^2_g-n^2_m)\,n^2_p\,w^2-(n^2_m-n^2_p)\,n^2_g\,u^2+\underline{n^2_m\,(n^2_p+n^2_g)}\}^2$$
$$-\underline{4\,n^2_g\,n^2_m\,n^2_p}\,\{(n^2_g-n^2_m)\,w^2-(n^2_m-n^2_p)\,u^2+\underline{n^2_m}\}$$
$$=A^2\,(n_g+x)^2\,n^4_p\,w^4+C^2\,(n_p+x)^2\,n^4_g\,u^4+B^2\,x^4\,(n_g+n_p)^2$$
$$-2\,AC\,(x+n_p)\,(x+n_g)\,n^2_p\,n^2_g\,u^2\,w^2$$
$$-2\,AB\,(x+n_g)\,x^2\,n^2_p\,w^2\,(n_g+n_p)$$
$$-2\,BC\,(x+n_p)\,x^2\,n^2_g\,u^2\,(n_g+n_p). \qquad (7)$$

Par cette transformation,[1] à cause des facteurs constants A^2, C^2, B^2, etc., N^2-4MP a tous ses termes du sixième ordre et le dénominateur est du sixième ordre; en divisant haut et bas par x^6, et passant à la limite, on obtient 4 pour le dénominateur et, après simplification,

$$X^2_{\text{lim.}}=A^2\,w^4+C^2\,u^4+B^2-2\,ACu^2\,w^2-2\,ABw^2-2\,BCu^2. \qquad (8)$$

Introduisons dans cette expression les angles θ et θ' que la direction u, v, w fait avec les normales aux sections cycliques limites, normales dont les cosinus directeurs sont respectivement[2]

$$\sqrt{\frac{C}{B}},\quad 0,\quad \sqrt{\frac{A}{B}}$$
$$-\sqrt{\frac{C}{B}},\quad 0,\quad \sqrt{\frac{A}{B}};$$

ces angles sont donnés par

$$\sqrt{B}\,.\cos\theta=w\,\sqrt{A}+u\,\sqrt{C},$$
$$\sqrt{B}\,.\cos\theta'=w\,\sqrt{A}-u\,\sqrt{C};$$

et, comme (8) peut s'écrire

$$X^2_{\text{lim.}}=(Aw^2+Cu^2-B+2uw\,\sqrt{AC})\,(Aw^2+Cu^2-B-2uw\,\sqrt{AC})$$
$$=\{B-(w\,\sqrt{A}+u\,\sqrt{C})^2\}\,\{B-(w\,\sqrt{A}-u\,\sqrt{C})^2\}, \qquad (9)$$

on en conclut

$$X_{\text{lim.}}=B\sin\theta\sin\theta', \qquad (10)$$

qui est la formule approximative habituelle.

Seconde expression exacte de la biréfringence.

L'expression (7) peut être décomposée en deux facteurs;[3] en opérant comme sur (8) et en tenant compte de (2), on obtient

$$\sqrt{N^2-4MP}=B\,(n_g+n_p)\,n^2_m\sin\theta\sin\theta'; \qquad (11)$$

[1] La partie essentielle de cette transformation, qui change $n^2_g+n^2_p$ en $n^2_g-n^2_p$, est soulignée.

[2] D'après la formule (1).

[3] En ajoutant et retranchant $4\,AC\,(x+n_p)\,(x+n_g)\,n^2_p n^2_g u^2 w^2$, on obtient une

de sorte que (6) devient

$$X = \frac{B\,(n_g + n_p)\,n^2{}_m \sin\theta \sin\theta'}{\sqrt{\Sigma n^2{}_p \cos^2\alpha\,(\Sigma n^2{}_m\, n^2{}_g \sin^2\alpha + 2 n_g\, n_m\, n_p \sqrt{\Sigma n^2{}_p \cos^2\alpha})}}. \quad (12)$$

Dans cette expression θ et θ' représentent des angles variables avec n_m, tandis que dans (10) θ et θ' sont les limites de ces angles lorsque l'indice moyen devient infini.

Formule à choisir pour le calcul numérique de la biréfringence exacte. Je prendrai comme exemple une face du *péridot*, minéral donné par

$$n_g = 1{,}697, \quad n_m = 1{,}678, \quad n_p = 1{,}661\,;$$

la face est donnée par

$$\alpha = 53^\circ\,54', \quad \beta = 59^\circ\,50'\,; \quad \text{d'où : } \gamma = 50^\circ\,44'\,58'',256.^1$$

On calcule

$$\Sigma n^2{}_p \cos^2\alpha = 2{,}8216496$$
$$\Sigma n^2{}_m\, n^2{}_g \sin^2\alpha = 15{,}8909546.$$

La formule (5) est impropre au calcul numérique parce qu'elle donne X^2, qui est de l'ordre des millionièmes, par la différence de deux nombres plus grands que l'unité ; or, les tables de logarithmes ne pouvant fournir qu'un certain nombre de figures, les chiffres deviennent incertains là où ils doivent être utilisés. Ainsi, en écrivant

$$X^2 = \frac{N}{M} - 2\sqrt{\frac{P}{M}},$$

on obtient :

$$\frac{N}{M} = 5{,}6317964$$

$$2\sqrt{\frac{P}{M}} = 5{,}6314712$$

$$X^2 = 0{,}0003252\,;$$

d'où

$$X = 18 \text{ millièmes.}$$

La formule (12) ne présente pas ces inconvénients, parce que les nombres presque égaux se trouvent au dénominateur à l'état de somme

différence de carrés. Si l'on continue la décomposition, on obtient une formule utilisable sous la forme approximative (9) n'exigeant pas le calcul de θ et θ' :

$$X^2{}_{\text{lim.}} = (\sqrt{B} + w\sqrt{A} + v\sqrt{C})\,(\sqrt{B} + w\sqrt{A} - u\sqrt{C})\,(\sqrt{B} - w\sqrt{A} + u\sqrt{C})\,(\sqrt{B} - w\sqrt{A} - u\sqrt{C}).$$

Dans le cas de la face du péridot traitée ci-après, on a :

$A = 19$, $B = 36$, $C = 17$, $w\sqrt{A} = 2{,}76$, $u\sqrt{C} = 2{,}43$, $\sqrt{B} = 6$

$$X^2{}_{\text{lim.}} = 11{,}19 \,.\, 6{,}33 \,.\, 5{,}67 \,.\, 0{,}81 = 325{,}31\,;\ \text{d'où } X_{\text{lim.}} = 18 \text{ millièmes.}$$

[1] C'est la face $e_3 = 121$.

et que le numérateur est un petit nombre pouvant être précisé avec beaucoup d'approximation. Ainsi, dans notre cas, on obtient

$$\log. N = \bar{1},23278174$$
$$\log. D = 0,97633527$$
$$\log. X = \bar{2},25644647$$
$$X = 0,0180487$$

ou, en millièmes,

$$X = 18,0487.$$
$$\text{vraie}$$

La presque égalité des quantités $\frac{N}{M}$ et $2\sqrt{\frac{P}{M}}$, qui revient à la presque égalité de $\Sigma n^2{}_m n^2{}_g \sin^2 a$ et $2 n_g n_m n_p \sqrt{\Sigma n^2{}_p \cos^2 a}$, suggère une simplification de la formule (12), qui peut s'écrire approximativement

$$X = \frac{B(n_g + n_p) n^2{}_m \sin\theta \sin\theta'}{\sqrt{2\,\Sigma n^2{}_p \cos^2 a \,.\, \Sigma n^2{}_g n^2{}_m \sin^2 a}}.$$

Dans notre cas, cette formule donne

$$X = 18,0485.$$

Les formules limites donnent :

$$V = 43°\ 24'\ 27'',47, \quad \theta = 30°\ 10'\ 10'',81, \quad \theta' = 86°\ 51'\ 37'',63$$
$$X_{\text{lim.}} = 18,0651.$$

Voici un exemple dans lequel on passe de la biréfringence X mesurée dans une face d'orientation connue à la vraie biréfringence B ; je choisis un cas où la biréfringence est extrême, cas dans lequel la formule limite ne suffit pas, et où il faut donc connaître l'indice moyen pour l'emploi de la formule exacte ; or, on verra que la connaissance de l'indice avec un seul chiffre décimal suffit pour résoudre la question.

Problème. — *On a mesuré la biréfringence X dans une face oblique à l'axe d'un cristal optiquement uniaxe et négatif. En déduire la vraie biréfringence $B = n_g - n_p$.*

Le corps est la calcite ; la face est son clivage, dont la normale est inclinée sur l'axe optique sous un angle de 44° 37'. La biréfringence mesurée est

$$X = 93,6 \text{ millièmes ;}$$

on a obtenu pour l'indice ordinaire

$$1,6 < n_g < 1,7.$$

Ici l'ellipsoïde est de révolution autour de l'indice n_p dirigé suivant l'axe x. La formule relative aux uniaxes pourrait être obtenue en faisant dans (12) :

$$n_m = n_g, \qquad \theta = \theta' = a ;$$

mais le calcul est assez long et il vaut mieux remonter à l'équation (3) : lorsque dans celle-ci on fait $n_m = n_g$, le premier membre devient divisible par $n^2 - n^2{}_g$ et l'on obtient pour la valeur du petit indice de la section

$$n = \frac{n_g n_p}{\sqrt{n^2{}_p \cos^2 a + n^2{}_g \sin^2 a}}, \tag{13}$$

puis

$$X = n_g - n = n_g \left(1 - \frac{n_p}{\sqrt{n^2{}_p \cos^2 a + n^2{}_g \sin^2 a}}\right).$$

Pour obtenir la formule inverse, on tire de (13)

$$n_p = \frac{n n_g \sin a}{\sqrt{n^2{}_g - n^2 \cos^2 a}} ;$$

on a alors

$$B = n_g - n_p = n_g \left(1 - \frac{(n_g - X)\sin a}{\sqrt{n^2{}_g - (n_g - X)^2 \cos^2 a}}\right).$$

En remplaçant dans cette formule X par les valeurs mesurées et en y faisant $a = 44° 37'$, on obtient la valeur de la biréfringence ; or,

pour $n = 1{,}6$ on trouve $B = 174{,}46$
„ $n = 1{,}7$ „ $B = 175{,}27$

et la vraie biréfringence de la *calcite* est $B = 175$.

La formule limite (10) devient ici

$$B = \frac{X}{\sin^2 a} = 189{,}74.$$

Voici différentes valeurs obtenues pour n_p et pour B, lorsque n_g croit depuis 1,5 jusqu'à ∞.

n_g	1,5	1,6	1,658	1,7
n_p	1,326447	1,425542	1,483063	1,524734
B	173,55	174,46	174,94	175,27

n_g	1,8	1,9	2	∞
n_p	1,624006	1,723349	1,822751	∞
B	175,99	176,65	177,25	189,74

Les nombres exacts pour la *calcite* sont

$$n_g = 1{,}658, \quad n_p = 1{,}483; \qquad \text{d'où } B = 175;$$

on en déduit, pour la biréfringence du clivage,

$$X = 93{,}6364;$$

nous avons pris 93,6 parce qu'une si haute biréfringence est déjà très difficile à obtenir pratiquement à un dixième près; ceci explique les légères divergences avec les nombres réels des valeurs de n_p et B, relatives à $n_g = 1{,}658$, que l'on observe dans le tableau qui précède.

Sur une propriété numérique de l'ensemble des axes de symétrie situés dans les plans de symétrie d'un polyèdre.

Par G. Cesàro.

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[Read January 26, 1915.]

LES axes de symétrie d'un polyèdre ne sont pas toujours situés tous dans ses plans de symétrie; ainsi, tandis que le cube a tous ses axes

$$3\,A^4, \quad 4\,A^3, \quad 6\,L^2$$

situés dans ses plans de symétrie, le rhomboèdre

$$A^3, \quad 3\,L^2$$

a son A^3 situé dans des plans de symétrie, tandis que les $3\,L^2$ ne sont pas situés dans ces plans.

Or, si l'on considère l'ensemble des axes situés dans les plans de symétrie,

$$3\,A^4, \quad 4\,A^3, \quad 6\,L^2 \text{ dans le premier cas,}$$
$$A^3 \text{ dans le second,}$$

j'ai trouvé que le symbole obtenu possède une propriété numérique remarquable: 'Si l'on multiplie chaque coefficient (nombre d'axes de même ordre) par l'ordre de l'axe et par cet ordre diminué d'une unité, que l'on ajoute ces produits partiels, que l'on multiplie par 4 la somme, et que l'on ajoute une unité au résultat, on obtient toujours un carré parfait. En outre, en divisant par 2 la racine de ce carré augmentée d'une unité, le résultat représente le nombre total des plans de symétrie possédés par le polyèdre.'

Ainsi, pour le cube, on a

$$4\,(3\,.\,4\,.\,3 + 4\,.\,3\,.\,2 + 6\,.\,2\,.\,1) + 1 = 289 = 17^2,$$

et le nombre de plans de symétrie est

$$\frac{17+1}{2} = 9;$$

pour le rhomboèdre, on obtient

$$4\,(1\,.\,3\,.\,2) + 1 = 25 = 5^2,$$

et, pour le nombre de plans de symétrie,

$$\frac{5+1}{2} = 3.$$

Voici la démonstration de cette propriété :

THÉORÈME. *Si*

$$N\,.\,\Lambda^n, \quad P\,.\,\Lambda^p, \quad Q\,.\,\Lambda^q, \ldots$$

est l'ensemble des axes de symétrie qu'un polyèdre contient dans ses plans de symétrie, le nombre

$$4\,\{Nn\,(n-1) + Pp\,(p-1) + Qq\,(q-1) + \ldots\} + 1 = C^2$$

est un carré parfait, et le nombre de plans de symétrie que le polyèdre possède est

$$X = \frac{C+1}{2}\,.$$

En effet, si l'on considère un premier plan de symétrie et que l'on désigne respectivement par

$$N_1, \quad P_1, \quad Q_1, \ldots$$

les nombres de Λ^n, Λ^p, Λ^q, ... y contenus, j'ai démontré [1] que le nombre total de plans de symétrie du polyèdre est donné par la formule

$$X = 1 + N_1\,(n-1) + P_1\,(p-1) + Q_1\,(q-1) + \ldots.$$

La même formule, appliquée successivement à tous les autres plans de symétrie du polyèdre, donnera de même

$$X = 1 + N_2\,(n-1) + P_2\,(p-1) + Q_2\,(q-1) + \ldots$$
$$X = 1 + N_3\,(n-1) + P_3\,(p-1) + Q_3\,(q-1) + \ldots$$
$$\ldots\ldots\ldots\ldots\ldots\ldots$$
$$\ldots\ldots\ldots\ldots\ldots\ldots$$

En ajoutant membre à membre ces X équations il vient

$$X^2 = X + (n-1)\,\Sigma N_1 + (p-1)\,\Sigma P_1 + (q-1)\,\Sigma Q_1 + \ldots. \qquad (1)$$

Mais, dans la somme $N_1 + N_2 + \ldots$ chaque Λ^n se rencontre n fois, car on sait qu'il est situé à l'intersection de n plans de symétrie,[2] de sorte que

$$\Sigma N_1 = nN, \quad \Sigma P_1 = pP, \ldots;$$

donc, en posant

$$Nn\,(n-1) + Pp\,(p-1) + Qq\,(q-1) + \ldots = S,$$

[1] G. Cesàro, 'Des macles.' Mémoires couronnés et mémoires des savants étrangers publiés par l'Académie royale de Belgique, 1893, t. liii, p. 47.

[2] Par un Λ^n, ou bien il passe n plans de symétrie, ou bien il n'en passe aucun et, d'après l'énoncé, on se trouve ici dans le premier cas.

l'équation (1) devient

$$X^2 - X - S = 0.$$

On en tire

$$X = \frac{1+\sqrt{4S+1}}{2}.$$

Comme X est un nombre rationnel, il s'ensuit que

$$4S+1 = C^2$$

est un carré parfait et que le nombre total de plans de symétrie est

$$X = \frac{C+1}{2}.$$

C'est la propriété qu'il fallait démontrer.

Exemples :

1° Considérons la combinaison axiale

$$3\,\Lambda^2, \quad 4\,\Lambda^3. \tag{2}$$

(*a*) Si seulement les $3\,\Lambda^2$ se trouvent dans des plans de symétrie,

$$4S+1 = 4\,(3\,.\,2\,.\,1)+1 = 25$$

$$X = \frac{5+1}{2} = 3.$$

Ce sont les polyèdres du groupe hexadiédrique

$$C, \quad 3\,\Lambda^2, \quad 4\,\Lambda^3$$
$$3\,\Pi$$

(*b*) Si les $4\,\Lambda^3$, et par conséquent les $3\,\Lambda^2$ aussi, se trouvent dans des plans de symétrie, la formule donnera le nombre maximum de plans de symétrie que peut présenter la combinaison axiale (2) :

$$4S+1 = 4\,(3\,.\,2\,.\,1 + 4\,.\,3\,.\,2) + 1 = 121$$

$$X = \frac{11+1}{2} = 6.$$

Ce sont les polyèdres du groupe tétraédrique

$$3\,\Lambda^2, \quad 4\,\Lambda^3, \quad 6\,P.$$

2° Considérons, en second lieu, la combinaison axiale

$$\Lambda^3, \quad 3\,L^2. \tag{3}$$

(*a*) Si seulement le Λ^3 se trouve dans les plans de symétrie, on obtient par la formule les trois plans de symétrie qui passent par l'axe ternaire, et l'on arrive aux polyèdres du groupe rhomboédrique holoédrique

$$C, \quad \Lambda^3, \quad 3\,L^2$$
$$3\,P.$$

(*b*) Si tous les axes de symétrie se trouvent dans des plans de symétrie, la formule donnera le nombre maximum de plans de symétrie que peut posséder la combinaison axiale (3) :

$$4S+1 = 4(3.2+3.2.1)+1 = 49$$

$$X = \frac{7+1}{2} = 4.$$

On obtient la combinaison

$$\Lambda^3, \quad 3L^2, \quad 3P'$$
$$\Pi$$

réalisée, par exemple, dans le prisme régulier à base triangulaire.

Autre énoncé de la propriété. En examinant ce qui vient d'être dit, on aperçoit un autre énoncé, tout aussi intéressant que le premier, de la propriété dont nous nous occupons :

Comme toutes les combinaisons axiales possibles sont susceptibles de posséder des plans de symétrie passant par tous les axes de symétrie, il s'ensuit que la propriété

$$4S+1 = \text{carré parfait}$$

est une condition d'existence d'une combinaison axiale quelconque, c'est-à-dire que l'on peut énoncer :

Pour qu'une combinaison axiale

$$N.\Lambda^n, \quad P.\Lambda^p, \quad Q.\Lambda^q, \ldots$$

puisse exister, il faut qu'en désignant par S la somme

$$S = Nn(n-1)+Pp(p-1)+Qq(q-1)+\ldots$$

la quantité $4S+1$

soit un carré parfait. Le nombre maximum *de plans de symétrie que la combinaison axiale dont il s'agit peut posséder est donné par la formule*

$$X = \frac{\sqrt{4S+1}+1}{2}.$$

On peut transformer les expressions de S et X comme il suit : Si γ est le nombre de positions identiques en apparence que le polyèdre considéré peut occuper dans l'espace, k_n le nombre d'espèces d'axes simples λ^n, k_p le nombre d'espèces d'axes simples λ^p, etc., on sait que[1]

$$\gamma = \frac{2Nn}{k_n} = \frac{2Pp}{k_p} = \ldots,$$

[1] G. Cesàro, 'Des polyèdres qui peuvent occuper dans l'espace plusieurs positions identiques en apparence.' Mém. couronnés et Mém. des savants

de sorte que

$$S = \frac{\gamma}{2}\{(n-1)k_n + (p-1)k_p + \ldots\}$$

et

$$4S + 1 = 2\gamma\Sigma(n-1)k_n + 1.$$

Donc : *Dans tout polyèdre, si l'on multiplie le nombre d'espèces d'axes simples d'un certain ordre par cet ordre diminué d'une unité, que l'on multiplie la somme de ces produits, obtenus pour tous les ordres, par le double du nombre de positions identiques en apparence que le polyèdre peut occuper dans l'espace, le résultat augmenté d'une unité donne un carré parfait.*

Le nombre maximum de plans de symétrie, que peut posséder la combinaison axiale considérée, est donc

$$X = \tfrac{1}{2}\{1 + \sqrt{2\gamma\Sigma(n-1)k_n + 1}\}.$$

Nombre maximum de plans de symétrie dans les trois classes de polyèdres. On sait que les polyèdres peuvent être rangés en trois classes, suivant qu'ils possèdent *trois* ordres d'axes, *deux* ou *un seul* ordre.[1]

1re *Classe.* Dans chaque ordre tous les axes sont de même espèce :

$$k_n = k_p = k_q = 1,$$
$$X = \tfrac{1}{2}\{1 + \sqrt{2\gamma(n+p+q-3)+1}\}.$$

2e *Classe.* Dans l'un des ordres les axes sont tous de même espèce, dans l'autre ils sont de deux espèces différentes :

$$k_n = 1, \quad k_p = 2,$$
$$X = \tfrac{1}{2}\{1 + \sqrt{2\gamma(n+2p-3)+1}\}.$$

3e *Classe.* On a : ou bien un axe unique hétéropolaire $\lambda^n\,\lambda'^n$, donc $k_n = 2$, $\gamma = n$ et par conséquent $X = n$; ou bien trois axes binaires perpendiculaires deux à deux :

$$(\lambda\lambda)^2, \quad (\lambda'\lambda')^2, \quad (\lambda''\lambda'')^2,$$

donc $k_n = 3$, $n = 2$, et comme $\gamma = 4$, $X = 3$.

étrangers publiés par l'Académie royale de Belgique, 1893, t. liii, p. 13, Théor. VIII. — Il faut observer que dans le mémoire cité ci-dessus N représente le nombre total d'axes simples λ^n, nombre qui est double de celui des axes composés Λ^n, de sorte qu'avec la notation employée dans le présent mémoire le nombre total de λ^n est $2N$.

[1] Loc. cit., pp. 15 à 22. — Ce sont les *trois classes* de polyèdres *possédant des axes de symétrie* ; une quatrième classe est celle des polyèdres sans axes de symétrie ; ces derniers polyèdres ne peuvent évidemment posséder tout au plus qu'*un plan de symétrie*, car l'intersection de deux plans de symétrie donnerait un axe de symétrie.

On crystals of Albite from Alp Rischuna, and pericline twins from La Fibbia, Switzerland.

(*With Plate VII.*)

By W. J. Lewis, M.A., F.R.S.

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[Read November 10, 1914.]

THE Cambridge Museum recently acquired a number of albite specimens from Alp Rischuna, near Vals Platz in Switzerland. Many of the crystals had good faces, so that measurement of the angles seemed likely to give trustworthy crystal-elements. The forms observed by me are:—

$b(010)$, $z(1\bar{3}0)$, $m(1\bar{1}0)$, $t(110)$, $f(130)$, $n(0\bar{2}1)$, $c(001)$, $y(20\bar{1})$, $o(\bar{1}\bar{1}1)$, $p(\bar{1}11)$, $\eta(\bar{1}\bar{3}1)$, $\delta(\bar{1}\bar{1}2)$, $x(\bar{1}01)$; and on the pericline crystals $\lambda(\bar{3}\bar{3}2)$ and $r(40\bar{3})$. Most of them are shown in Plate VII, figs. 1 and 2.

In his 'Minéralogie', 1862, Des Cloizeaux gives the fullest account known of Swiss albites, his determination being largely based on the measurement by Marignac of numerous crystals from St. Gotthard. What precise locality they came from is unknown, for the term is often used by dealers and collectors to denote places far removed from the Pass. Albite is common throughout the whole of the Central Alps, but measurable crystals are rare. My results differ greatly from those of Des Cloizeaux, and this is to some extent due to the dependence placed by him on the angles made by $b(010)$ and $c(001)$ with one another and with other faces. Three of his fundamental angles are *bn*, *cn*, and *cm*; and, as will be seen from what follows, these angles are very untrustworthy.

Des Cloizeaux and other authors remark on the fact that the face *b* is displaced in the vertical zone [*bmt*] in such a way that the two faces *b*, which should be parallel, make a thin wedge whose edge is to the front. On one of my crystals, which seemed at first sight to be a twin with the

normal to (100) as axis of rotation and (010) as combination-face, the angle between the two *b* faces closely accords with that required by such a twin. Examination showed, however, that a very thin lamina was twinned to the one on its left according to the albite law and to that on its right according to the Carlsbad law; the extreme portions being then in a relative position with respect to one another as if twinned about an axis perpendicular to the axis *OZ* and parallel to the face (010). Plate VII, fig. 3, represents such a twin, in which the lamella sandwiched between the other twin components has an appreciable thickness. Dreyer and Goldschmidt say that the face *b* on their crystals is accurately in the zone [*mt*]. This I have found to be frequently the case on Rischuna crystals, but not always so; and the faces *b*, *z*, *m* of one individual are often distinctly out of the zone of the homologous faces on the second, though the deviation from tautozonality is small. As the inclination of the zones [*bzm*] and [*bn*] is about $63\frac{1}{2}^\circ$, it is clear that *bn* should not be used as a fundamental angle.

The face *c* is often divided into segments, each of which gives a separate bright image. The parallel cleavage is almost always uneven, and often gives two images, neither of which is parallel to any image on the natural face. Melczer blackened parts of the face and so obtained a single reading, but it does not follow that this was correct. In one case I obtained a brilliant even cleavage comparable with that often seen in calcite, but its position did not satisfy what I deem its true one. In this crystal the faces *b* and *n* also gave good images, which lie in a zone with *c* and the cleavage c_1. The angles made are:—$c_1b = 86^\circ\ 32\frac{1}{2}'$, $bn = 46^\circ\ 35'$; but $c_1c = 179^\circ\ 4\frac{1}{2}'$ or $179^\circ\ 11'$. If the cleavage be accepted as true and the natural face ignored, we should get for *cn* the angle $46^\circ\ 53'$. But the other zones on this crystal are not of such goodness as to justify the rejection of the measurements on other equally good and even better crystals. The above crystal is interesting in another way, for it supplies a good instance of what I have noticed in other cases. This is that we cannot judge of the correctness of an angle by the brightness and clearness of the images; for *m* gives two images, one brilliant and good, the other faint. The angle *bm* (bright) is $59^\circ\ 6\frac{1}{2}'$, that to the faint image is $59^\circ\ 40'$. Again, in the zone [*ymn*] the bright image is out of the zone and makes with *y* an angle of $42^\circ\ 54'$, whilst the faint image is in adjustment and its inclination to *y* $42^\circ\ 34'$. The face *n* gives in this zone two images separated by $5'$.

The faces which gave the most trustworthy measurements are *y*, *n*, *z*, and *m*. The zone [*ymno*] is throughout fairly trustworthy; the similar

zone [$tc\delta o$] is far less good, and but little dependence has been placed on it. Des Cloizeaux points out that t is untrustworthy. He says: 'Sur les petits cristaux d'albite la face t ne se trouve jamais exactement dans la zone $pb^1b^{\frac{1}{2}}[c\delta o]$...; d'après les indications du goniomètre, le plan qui ferait partie de cette zone serait compris entre t et u.' Both m and t frequently give two or three images, and under a strong lens the faces are often seen to be composite. In some cases it has been impossible to disentangle the angle mt from the twin-angles $m\underline{m}$ and $t\underline{t}$. I think also that in other cases each of the faces is to some extent false in the same way as is that face on Carlsbad twins of orthoclase, where adjacent portions of c and x are coplanar, although on simple crystals the inclination of these faces to the vertical differs by as much as 1° 54′.

My solution of the Rischuna crystals is based on the two triangles myt and znm, which have a common angle $tmy = zmn = 56° 34{\cdot}2'$. After much trial the following angles were adopted:—

mt 52° 16½′, mz 29° 36′, my 42° 26′, ty 45° 50½′, mn 51° 21′.

The other angles in the zone [$ymno$] were utilized in fixing the values of my and mn, for the four faces make a harmonic ratio. Unfortunately no good faces could be found in other zones which might serve to check the values ascribed to the other fundamental angles. For though the zone [zn] has four faces in it, $p(\bar{1}11)$ is so poor and so much out of place that the angles from it to other faces were valueless. Again, the face $\eta(\bar{1}31)$ is very narrow and dull, and the angles it makes with other faces serve only to establish its symbol. The face $\delta(\bar{1}\bar{1}2)$ is in some cases largely developed and then gave a good image, but it generally gave two; $o(\bar{1}\bar{1}1)$ is a large uneven face, not in all parts bright, which usually gave two images. It will be noticed that the agreement of the observed means of angles in the zone [$c\delta o$] with the computed values is not very close. The face $x(\bar{1}01)$ is very poor and ill-developed, and a worthless reading from it was only got in one or two cases. A rounded face r in the zone [cy], similar to that mentioned by Des Cloizeaux, was largely developed on some of the crystals, but no measurements of any value could be made. On one of the pericline crystals, described later on, a fairly good reading corresponding to (403) was obtained, and in figs. 1 and 2 this symbol has been adopted for the face.

Since 1862 many memoirs on albite-crystals from different localities have appeared, the references to some of which are given in the foot-note.[1]

[1] G. Melczer, Földtani Közlöny, Budapest, 1905, vol. xxxv, p. 153; translation in Zeits. Kryst. Min., 1905, vol. xl, p. 571. S. Glinka, Russ. Bergjournal,

That of Melczer describes very good crystals from Nadabula in Hungary, and gives a fairly full account of the work published by others up to 1905. The memoir of Dreyer and Goldschmidt describes crystals of unusual excellence from Greenland, but, though full and exhaustive, their paper has not been so useful as Melczer's, for the observations were made with a two-circle goniometer, and the only interfacial angles measured were those of the prism-zone. In my tables I have given Melczer's observed angles, and also under the heading 'D. & G.' a table of angles computed by me from the two-circle readings. Glinka's papers on albite-crystals from Russian localities are inaccessible to me, and the abstracts in Groth's 'Zeitschrift' are unfortunately full of misprints.

Melczer's crystals have much the habit of those from Alp Rischuna, and his diagrams can serve very well for many of my crystals. A common habit is that of two distinct individuals, such as those shown in figs. 1 and 2, twinned according to the albite law and with a pair of good t faces which make, according to him, a re-entrant angle of 58° 47·6′. The mean of twelve readings of this angle on my crystals is 58° 34′, and its computed value 58° 3′. In both his and my crystals the faces t are often very small, and in some cases disappear entirely, when the prism-zone resembles one of a crystal of the prismatic system with b, z, and m shown on both sides of the twin-plane acting as one of symmetry. At the back of some crystals I obtained $f(130)$ and a cleavage parallel to t. The face $x(\bar{1}01)$ seems to be well developed on Nadabula crystals, for Melczer gives the observed angles xy, xo, xm, and $x\delta$. The large rounded face $r(40\bar{3})$ also gave him a fair angle.

In determining the elements and theoretical angles of our crystals Melczer and I proceeded on closely parallel lines. We both begin by adopting values for mt and mz, from which all other angles in their zone are deduced. We then adopt values of the angles made by n and y with one another and with certain of the faces in the prism-zone, and then compute other interfacial angles from the triangles which are thus established in succession. Melczer gives a table of several readings of ten of his principal angles, of which the means and adopted values, as also my observed values, are given in the following table :—

1889; abstract in Zeits. Kryst. Min., 1894, vol. xxii, p. 63. C. Dreyer and V. Goldschmidt, Meddelelser om Grønland, 1910, vol. xxxiv, p. 1; reprinted in Neues Jahrb. Min., 1910, Beil.-Bd. xxix, p. 537. C. Viola, Min. Petr. Mitt., 1895, vol. xv, p. 135.

Angle.	Melczer.			Lewis.	
	No. of readings.	Observed means.	Adopted values.	Observed means.	
				Rischuna.	Fibbia.
zm	17	29° 49′	29° 49·8′	29° 35′	29° 53′
mt	5	59 17·9	59 17·9	59 16¼	59 19
zn	2	40 51½	40 55	40 59	40 47
my	6	42 26·4	42 28·2	42 28	42 25
mn	5	51 20·5	51 22·4	51 20½	51 19½
no	4	47 1½	46 58·4	46 56	—
mo	12	98 21	98 20¾	98 17	—
xy	2	150 3¼	150 4⅓	—	150 4
cy	2	97 54½	97 52	97 54	97 43½
mc	5	69 53	69 5⅓	69 5	68 45

It will be noticed that the only serious divergence between our observations occurs in *zm*. The value found by me is exceptionally low, but it is in my belief much more trustworthy than *mt*. Melczer and I differ in the triangles which we use in succession. His order seems to have been, *mzn*, *bmo*, *bmn*, *bzn*, &c. Mine is *myt*, *mzn*, *zyt*, *zym*, *otm*, &c. Melczer clearly laid stress on the readings from *b*, but does not seem to have used *t* to any extent, whereas I have given it great weight. He says that he made some use of the angles between like faces on the pair of twinned individuals. These angles, even in the best crystals, are of such doubtful value that I did not allow them any weight. In most cases the agreement between the observed and computed values of the thirty-four angles given in his final table is good, save in the angles which involve (010) and (001). It is unfortunate that he does not give the angle *zy*, for it is in my crystals a good angle and serves as a useful check on the correctness of the angles in the triangle *ymt*. Again, the only angle involving $p(\bar{1}11)$ given by him is *bp*, and one is unable to judge of the value of the face. I did not often find the faces *b*, *p*, *o*, and *x* tautozonal. There can, however, be no hesitation in accepting Melczer's crystal-elements as very close approximations to the true values for Nadabula crystals; but the claim that the angles are correct to an accuracy of $\pm 1'$ is open to question, seeing that in so good an angle as *zn* there is a difference of $3\frac{1}{2}'$ between the theoretical and observed values.

It is a curious fact that my observed value differs from that adopted by exactly the same error, especially as it seems to me one of the three or four most trustworthy angles.

To the following linear and angular elements, as usually given, of the Rischuna and Fibbia crystals I have appended those of some of the principal observers:—

	a : *b* : *c*	*a*	*β*	*γ*
Lewis (Rischuna) ...	0·6335 1 0·5564	93° 58′	116° 21′	87° 31¼′
„ (Fibbia)	0·6354 1 0·5593	93 57½	116 37	87 57½
Melczer (Nadabula) ...	0·6350 1 0·5778	94 6	116 36⅓	87 52
D. and G. (Greenland) ...	0·6367 1 0·5593	94 15	116 37	87 41
Glinka (Kirebinsk) ...	0·6341 1 0·5574	94 5⅓	116 27	88 6¾
Viola (Crete)	0·635 1 0·557	94 14½	116 31¾	88 5
Lacroix-Des Cloizeaux (St. Gotthard)	0·633 1 0·557	94 3	116 27	88 9

The following are the values of my five fundamental angles either given by the above authors, or computed by me from their data:—

	mt	*mz*	*my*	*ty*	*mn*
Rischuna	59° 16½′	29° 36′	42° 26′	45° 50½′	51° 21′
Fibbia	59 19	29 53	42 25	45 43	51 19½
Nadabula	59 18	29 50	42 26½	45 52	51 22
Greenland ...	59 26	29 46	42 25½	45 49½	51 15½
Kirebinsk	59 18	29 46	42 35	—	51 34
St. Gotthard ...	59 13	29 57	42 27	45 42	51 36

I have much pleasure in thanking Mr. S. Kôzu and Mr. H. B. Cronshaw for valuable help. The former has determined the refractive indices and optic axial angle of the crystals; his results are published in the following memoir, and are plotted in Plate VII, fig. 4. They bear on their face evidence of much skill and great care. Mr. Cronshaw's analyses were made on material carefully selected and dried at 110° C., and one gram was used in each fusion. His results are:—

SiO_2	68·28
Al_2O_3	19·95
CaO	0·45
Na_2O	11·35
K_2O	0·06
Loss on ignition	0·10
	100·19

Multiple Manebach and Pericline Twins.

Some years ago I found on the Fibbia, at the summit of the St. Gotthard Pass, a number of small albite crystals, which are multiple twins according to the two above laws. Somewhat similar twins from Pfunders, Tyrol, were described by G. vom Rath,[1] and other like ones from the Weidalp, in the Habach Valley, Salzburg, by Professor Viola.[2] Plate VII, fig. 6, is a copy of a photograph of the best of these twins, which was made to show the arrangement of the edges between the faces *b* of the several individuals. Fig. 5 shows the specimen more completely and with a fair approximation to its actual development. The length of the crystal is about 12 mm., and the breadth of its face *c* about 6 mm. It consists of two slightly unequal portions, which are twinned according to the Manebach law—twin-face (001). The edges, such as $[b_1b_2]$, in which these portions meet are parallel to the face *c*; and the angle b_1b_2 is a salient one of nearly 7° 45′. The portion labelled *b* is uneven, and there is some slight indication of lamellation parallel to *c*, but there are no salient or re-entrant angles such as characterize the lamellae shown so conspicuously in the photograph.

As shown in fig. 5, the uppermost portion above the slanting lamella seems to belong to a single individual bounded by the faces *c*, *b*, *f*, *t*, *m*, and *z*. There is no difficulty in discriminating between the faces *m* and *t*; for the former is bright and more or less regularly striated parallel to the edge $[mt]$, whilst *t* is dull, fairly even and free from striae. In the next place comes a fairly uniform lamella twinned to the upper portion according to the pericline law—twin-axis $OY = [cy]$. It slants across the right-hand half in such a direction that the combination-plane is parallel to a face lying between *c* and $x(\bar{1}01)$. In drawing the figure I have assumed this plane to be $(\bar{1}05)$, for such a plane makes an angle of 9° 41′ with (001). At the upper edges of the lamella the angles are alient, at the lower edges they are re-entrant. At the edge $[mt]$ the lamella widens out so as to occupy the whole of the left-hand part labelled $\underline{t}$. The upper limit of the lamella is continued across the upper individual, and is perceived in the edges $[m\underline{t}]$ and $[\underline{z}f]$, where the angles are re-entrant. The salient and re-entrant edges of the lamella seem fairly straight, but will not bear the test of close observation with the microscope even when the magnification is small; and, as is seen in both figures, the lamella thins out towards the back. Below the principal

[1] G. vom Rath, Monatsber. K. Akad. Wiss. Berlin, 1876.
[2] C. Viola, Zeits. Kryst. Min., 1900, vol. xxxii, p. 305.

lamella is a second much thinner and less uniform lamella in the same twin orientation as the first. It disappears in the midst of b_1 and $\underline{t}$. Finally, as shown by the shaded patch m in fig. 5, there is an irregular piece at the apex, where the original orientation transgresses the vertical edge. It is hence clear that the internal structure is much confused in the way described as intercrossing twin formation. Vom Rath represents the intercrossing of the Pfunders multiple twin as taking place very regularly, so that he shows four nearly equal intercrossing portions. He also states that on the faces b the pericline twin-edges were all re-entrant, both to right and left.

The lower half of the crystal bears letters with subscripts 2 and 3. The pericline twin-edge $[b_2 b_3]$ is somewhat uneven, and the angle is re-entrant. Parallel to it are two fine lamellae having the same orientation as the portion to which b_2 belongs, and their surfaces reflect the light simultaneously with b_2. As in the upper half the intercrossing of the pericline twin is irregular and takes place about midway across the joint face m_2 and t_3. The face m_2 (shaded in the wrong direction) is easily recognized in spite of the fact that its free growth seems to have been prevented. At the points where the faces $\underline{m}$ and m_2 meet the Manebach combination-plane, narrow shelves exist, each of which is parallel to the y face of the individual. They have been omitted, for their introduction would have uselessly confused the drawing.

Several other crystals on the specimen show similar multiple twinning —one at least seems to include a larger number of twinned portions, in which the Manebach law occurs twice.

As is well known, vom Rath gave as the combination-plane of the pericline twin the plane of the rhombic section. This plane satisfies the condition that there is no overlapping of the individuals, and that the prism-faces are congruent in edges. Further, he observed that, in accordance with the change in the crystal elements of albite and anorthite, the combination-plane in the former inclined upwards to the front whilst in anorthite it is inclined downwards. He brought as further proof that on one of his crystals the edge $[b\underline{b}]$ made with $[bc]$ an angle of 13°, agreeing with an angle of 13° 12′ computed by him from Breithaupt's angles for pericline. On another twin from Kragerö the angle was 22°, which he thought agreed with the angle computed from elements deduced in part from Schmirn crystals. Unfortunately an error crept into the computation, and the first computed angle should be 31° 29′, very nearly that needed by the Fibbia crystals.

To test the view that the rhombic section is the combination-plane

I have measured under the microscope the angle made by the edge [bc] with [$b\underline{b}$] that of pericline twinning. Only rough approximations were possible, and in different parts the angle varied between the limits of $7\frac{1}{2}°$ and 11°. As a fair approximation the face ($\bar{1}05$), inclined to c at 9° 41′, seems the best; and fig. 5 was drawn on the assumption that this is the combination-plane. From the crystal-elements obtained by me, the angle made by the rhombic section with c is 30° 53′; and the angle between [bc] and the twin-edge [$b\underline{b}$] would be 30° 57′, an angle clearly inconsistent with the observed values.

The crystals were all embedded in chlorite, and have suffered a certain amount of corrosion which has specially affected the faces t, λ, and o, and to a less degree the faces b and x. The faces c are not very bright; in some cases the parallel cleavage was obtained, and reflection from the artificial face was used in preference to that from the natural one. The crystals measured were all very small, and several of them showed pericline twinning. The faces m, z, n, and y, when present, were all fairly bright, but the three last were very small, whilst m is striated and often gave two images. None of the angles will, however, compare in goodness with those measured on the Rischuna crystals. No reflection could be got from t, but in one crystal (the only one on which λ has been found) I was fortunate enough to obtain a parallel cleavage, which gave me the angle $mt = 59° 19′$.

The very rare face $\lambda(\bar{3}\bar{3}2)$ is fairly large but has been corroded, so that the angles are only approximate. There can, however, be no doubt as to its presence in the two zones [tco] and [zy]. It is given by Des Cloizeaux as having been observed by Marignac on pericline, the angle $c\lambda = 74°$ being, however, marked as very questionable. My reading is 74° 52′, and the computed angle 75° 7′. It has also been observed on albite from Sterzing by Hessenberg, who deduced its symbol from the zones [cot] and [xf]. He adds that he is inclined to think that the face on his specimen was due to fine alternations of the faces t and o.

In order to determine the crystal-elements I had to employ the angles made by the cleavages parallel to c and t with the faces m, n, z, and y. After some trials the sides of the triangle cmt, the position of the pole A (100), and also the angle Ay were adopted; the values being:—

cm 69° 1′, ct 65° 15′, mt 59° 19′, Am 29° 35′, Ay 34° 19′.

The angles in the zone [bzm] were then found, and the triangles mty and mzy served as checks. The rest of the solution then followed the lines used with the Rischuna crystals. The principal observed and computed angles are given in the tables.

Angle.	Rischuna.				Fibbia.		Nadabula.	Greenland.
	Compd.	Obsd. means.	No. of readings.	Limits.	Compd.	Obsd.	Melczer. Obsd.	D. & G. Compd.
bz	30° 9′	29°51′	18	30°11½′ – 29°21′	30°16′	29°29′	29°42′	30°10′
bm	59 45½	59 34½	10	59 50½ – 58 57	60 7	59 47½	59 43	59 56
zm	*29 36	29 35	28	29 50 – 29 9½	29 51	29 53	29 50	29 46
mt	*59 16½	59 16	23	59 37 – 59 0	*59 19	59 19	59 18	59 26
ef	30 24	30 26½	3	30 35 – 30 25	30 9	...	*30 10	30 14
eb	60 58	60 53	6	61 27½ – 60 10	60 34	...	*60 36	60 38
Am	29 26½	...	...	... ...	*29 35	...	...	...
ym	*42 26	42 28	18	42 44½ – 42 18	*42 29	42 25	42 26½	42 25½
mn	*51 21	51 21½	20	51 30 – 51 10	51 21½	51 19½	51 22	51 15½
ym	93 47	93 48½	16	93 58 – 93 40	93 50½	93 41½	*93 50½	93 41
no	47 1	46 56	22	47 7 – 46 46	46 57½	...	47 1½	47 3
mo	98 22	98 17	21	98 28 – 98 2	98 19	...	98 21	98 19
yo	140 48	140 46	17	140 58 –140 31½	140 48	140 29	*140 49	140 44½
zn	40 55½	40 59	25	41 4½ – 41 53	40 49	40 47	40 51½	40 52
nδ	38 42½	38 34	24	38 47½ – 38 16	38 39	...	38 46½	38 48
zδ	79 38	79 33½	24	79 49½ – 79 17	79 28	...	*79 35½	79 40
zp	51 46½	51 35	10	51 38½ – 51 22½	51 50	51 44	*51 49	51 39½
cm	69 13½	69 5	18	69 25 – 68 51½	*69 1	68 59	69 5¼	69 10½
mp	54 48	54 43	9	54 59 – 54 29	54 56	54 55	...	54 53
cp	55 58½	...	...	... ...	56 3	55 50	...	55 56½
Ac	63 45¼	...	...	... ...	63 27½	...	...	63 28
cx	52 6½	...	...	... ...	52 19	52 58	52 16½	...
cr	65 17	...	...	... ...	65 33	66 20	...	...
cy	81 53	82 6½	16	82 20 – 81 51	82 13½	82 11	82 5½	82 7½
oy	29 46½	...	...	... ...	29 54½	29 56	29 57	...
c:$\bar{1}$05	...	...	...	... ...	9 41	...	...	...
c_1b	86 47½	86 35½	10	86 45 – 86 28	86 35½	86 36	...	...
bn	46 40	46 35	17	46 55 – 46 23	46 41	47 0	46 35½	46 47
nc	46 32¼	46 33	15	46 50 – 46 0½	46 43½	46 29	46 41	46 50
bc	93 12¼	...	...	... ...	93 24½	93 32	93 31	93 37
c_1t	114 30	114 52½	10	115 15½ –114 43	...	...	...	...
tc	65 30	65 23½	21	65 45 – 65 4½	*65 15	65 12	65 12½	65 7½
cδ	29 56¾	29 57	18	30 15 – 29 40	30 8½	...	30 6½	30 4
δt	95 27	95 19	18	95 40 – 94 30	95 23½	...	...	95 11
δo	27 26	27 30	17	28 4½ – 26 40½	27 37½	...	27 38	27 39
co	57 22¾	57 31	15	57 48 – 57 10½	57 46	57 28	57 41½	57 42½
to	122 53	122 55½	18	123 15½ –122 36	123 1	122 36	...	122 50
tλ	...	...	...	... ...	140 22	140 5	...	140 2
zy	62 44	62 44	15	62 55 – 62 22	63 1½	63 0	...	62 50
zη	54 13	54 27	5	55 10 – 54 2	54 6½	...	...	54 5
	...	...	...	... ...	33 6	33 17	...	...
ty	*45 50½	45 47	14	45 55½ – 45 40	45 45	45 43	45 52	45 59½
yp	38 57	39 8	8	39 34 – 38 48	39 18	...	...	39 16

Angle.	Rischuna.				Fibbia.		Nadabula.	Greenland.
	Compd.	Obsd. means.	No. of readings.	Limits.	Compd.	Obsd.	Melczer. Obsd.	D. & G. Compd.
tn	92 54½	92 50	13	93 1½ – 92 36	93 3	93 12	...	92 56
nη	35 7	35 17	1	... ...	...	...	...	35 16
bp	60 18	59 54½	5	60 5 – 59 47	60 20¾	60 30	60 8	60 3
bη	34 50	34 55	5	35 0 – 34 43	34 36	...	...	34 42½
bo	66 34½	66 41½	11	66 56 – 66 30	66 14½	66 23	66 34	66 31
bx	93 55¼	...	...	... ...	93 41¾	93 50	94 1	94 3
cr	79 56	80 9	6	... ...	79 58½	80 1½	...	80 12

Explanation of Plate VII.

Figs. 1 and 2.—Crystals of albite from Alp Rischuna, Switzerland, each showing two distinct individuals twinned according to the albite law (p. 178).

Fig. 3.—Crystal of albite from Alp Rischuna with an intercalated lamina twinned to the left-hand individual according to the albite law, and to the right-hand individual according to the Carlsbad law (p. 179).

Fig. 4.—Curves plotting the values of the three principal refractive indices and the optic axial angles for light of different wave-lengths of albite from Alp Rischuna. (See S. Kôzu, p. 191.)

Fig. 5.—Crystal of albite from La Fibbia, Switzerland, showing multiple Manebach and pericline twinning (p. 184).

Fig. 6.—Photographic reproduction of the same crystal.

The dispersion phenomena of Albite from Alp Rischuna, Switzerland.

(*With Plate VII, fig.* 4.)

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[Read March 16, 1915.]

Dispersion of the three principal refractive indices.

THE refractive indices of this mineral for different wave-lengths were determined by the Abbé-Pulfrich total-reflectometer. The dispersion of the glass hemisphere of the instrument was determined by the aid of a highly polished glass prism, the dispersion of the latter being found by the method of minimum deviation. In order to obtain light of definite wave-length Hilger's wave-length spectrometer was used with a Nernst lamp or an electric arc as the source of illumination.

The three principal refractive indices for sodium-light—α_{Na}, β_{Na}, γ_{Na}—were determined in the usual way, and I carefully noted the azimuths in the plate along which the corresponding critical angles were measured. These same azimuths then served for measuring the corresponding critical angles for all other wave-lengths, because in albite the dispersion of the elasticity-axes is very small and may be neglected so far as this method is concerned.

The critical angles and corresponding refractive indices for sodium-light, given in table I, were determined on seven different dates (ranging from November 1914 to January 1915). Adopting the arithmetic means, we have:—

$$\alpha_{Na} = 1{\cdot}5289$$
$$\beta_{Na} = 1{\cdot}5330$$
$$\gamma_{Na} = 1{\cdot}5392.$$

The optic axial angle computed from the above values is:—

$$2V_\gamma = 78^\circ\ 30{\cdot}5'$$

By direct observation:— $2V_\gamma = 78^\circ\ 39{\cdot}0'$.

Table I.

Observed critical angles and the corresponding Refractive Indices for sodium-light.

(Temperature 18°—20° C.)

	θ_α	α	θ_β	β	θ_γ	γ
1	53°59′25″	1·5289	54°12′ 5″	1·5330	54°31′ 7″	1·5391
2	53 59 15	1·5289	54 12 18	1·5331	54 31 51	1·5394
3	53 59 0	1·5288	54 12 15	1·5331	54 31 38	1·5393
4	53 59 7	1·5289	54 12 2	1·5330	54 31 31	1·5393
5	53 59 3	1·5289	54 12 13	1·5331	54 31 31	1·5393
6	53 59 7	1·5289	54 11 51	1·5330	54 31 15	1·5392
7	53 59 10	1·5289	54 12 1	1·5330	54 31 20	1·5392
Mean	53 59 9	1·5289	54 12 6	1·5330	54 31 29	1·5392

The critical angles for other wave-lengths were measured on two different days, and the values are given under I and II of table II.

Table II.

Observed critical angles.

(Temperature 17°—20° C.)

λ in $\mu\mu$	θ_α		θ_β		θ_γ	
	I	II	I	II	I	II
455·5	52°40′50″	...	52°54′15″	...	53°12′37″	...
486	53 6 41	53° 6′ 5″	53 19 26	53°19′33″	53 38 22	53°38′29″
508·5	53 21 22	53 21 34	53 34 30	53 34 41	53 53 7	53 53 15
527	53 32 44	53 32 21	53 45 4	53 45 5	54 4 4	54 4 3
535	53 36 37	53 36 27	53 48 54	53 49 34	54 8 26	54 8 3
554	53 45 34	53 45 16	53 58 7	53 58 2	54 17 37	54 17 1
589 (Na)	53 59 9	...	54 12 6	...	54 31 29	...
610	54 7 11	54 6 43	54 19 49	54 19 34	54 39 19	54 38 35
644	54 16 45	54 16 16	54 29 34	54 29 46	54 49 0	54 48 1
671	54 23 32	54 22 52	54 35 56	54 36 7	54 55 23	54 54 43
700	54 29 41	...	54 42 7	...	55 1 19	...

The two series of observations agree very closely; the greatest differences in the values of θ_γ occurring for the wave-lengths of 610, 644, and 671 $\mu\mu$, and in the values of θ_α for 610 $\mu\mu$. These differences do not, however, exceed one minute, which corresponds to a variation in the refractive index of about 0·0003. The arithmetic mean of each pair in

the two sets of critical angles was employed in the calculation of the corresponding refractive index. The mean critical angles and their variation from those for sodium-light are given in table III; and the refractive indices and birefringencies computed from them in table IV.

Table III.

Observed critical angles (means of I and II).

λ in μμ	θ_α	$\Delta\theta_\alpha$	θ_β	$\Delta\theta_\beta$	θ_γ	$\Delta\theta_\gamma$
455·5	52° 40′ 50″	1° 18′ 19″	52° 54′ 15″	1° 17′ 51″	53° 12′ 37″	1° 18′ 52″
486	53 6 23	52 46	53 19 29	52 37	53 38 31	52 58
508·5	53 21 23	37 41	53 34 36	37 30	53 53 11	38 18
527	53 32 33	26 36	53 45 5	27 1	54 4 4	27 25
535	53 36 32	22 37	53 49 12	22 54	54 8 15	23 14
554	53 45 25	13 44	53 58 5	14 3	54 17 16	14 13
589	53 59 9	0 0	54 12 6	0 0	54 31 29	0 0
610	54 6 56	7 47	54 19 43	7 37	54 39 2	7 33
644	54 16 31	17 22	54 29 40	17 34	54 48 36	17 7
671	54 23 12	24 3	54 36 2	23 56	54 55 3	23 34
700	54 29 41	30 32	54 42 7	30 1	54 1 19	29 50

Table IV.

Refractive Indices and Birefringencies.

(Temperature 17°—20° C.)

λ in μμ	α	β	γ	γ−α	γ−β	β−α
455·5	1·5373	1·5419	1·5481	0·0108	0·0062	0·0046
486	1·5347	1·5391	1·5455	0·0108	0·0064	0·0044
508·5	1·5331	1·5374	1·5435	0·0104	0·0061	0·0043
527	1·5321	1·5362	1·5424	0·0103	0·0062	0·0041
535	1·5315	1·5357	1·5419	0·0104	0·0062	0·0042
554	1·5305	1·5346	1·5408	0·0103	0·0063	0·0041
589	1·5289	1·5330	1·5392	0·0103	0·0062	0·0041
610	1·5283	1·5324	1·5385	0·0102	0·0061	0·0041
644	1·5268	1·5310	1·5370	0·0102	0·0060	0·0042
671	1·5260	1·5301	1·5360	0·0100	0·0059	0·0041
700	1·5254	1·5294	1·5354	0·0100	0·0060	0·0040

The above refractive indices are plotted in Plate VII, fig. 4, in which the abscissae give the wave-lengths in μμ units, and the ordinates give the corresponding refractive indices of the mineral and the liquid, the latter being the curve passing through black dots. It will be noticed that the dispersions of β and γ are very slightly greater than that of α, the two former being almost equal, though there seems to be a tendency for the

dispersion of γ to be the greater. The numerical values of the refractive indices obtained by the method are not, however, accurate enough for much dependence to be placed on the details of the dispersion. Table IV shows also that the dispersion of the principal birefringencies increases as the wave-length diminishes, although, again, no great dependence can be placed on the particular numbers.

Dispersion of the optic axial angle.

The optic axial angle was measured by the universal goniometer modified by Mr. A. Hutchinson, the dispersion of the liquid in which the mineral was immersed being determined by the total-reflectometer. The crystal-section was nearly parallel to the pinacoid (010); and to avoid the error arising from the obliquity of the section to the acute bisectrix, the section was immersed in a liquid—a mixture of cedarwood oil, methylene iodide, and monobromonaphthalene—whose refractive index was adjusted so as to be equal to β_{Na} of the crystal. Owing to the difference of the dispersions of the liquid and the crystal and to the difference in the inclination of the optic axes, A and B, to the crystal face, small errors enter into the observed angles 2H. These and their corrected values, 2V, in determining which the values found for the dispersions of the liquid and of β have been used, are given in table V. The changes in the optic axial angle with the wave-lengths are shown in the curves of Plate VII, fig. 4, marked 2H and 2V respectively.

Table V.

Dispersion of the optic axial angle.

(Temperature 16·2°—17·2° C.)

λ in $\mu\mu$	2H (= A $\wedge$ B)	2V	Liquid	β
486	78° 21·0′	78° 46·1′	1·5460	1·5391
508·5	78 26·0	78 43·3	1·5422	1·5374
535	78 33·0	78 43·2	1·5386	1·5357
589 (Na)	78 39·0	78 39·0	1·5330	1·5330
644	78 40·7	78 32·2	1·5287	1·5310
671	78 42·2	78 31·3	1·5271	1·5301

The present study was carried out in the Mineralogical Laboratory of the University of Cambridge. I desire to offer my sincere thanks to Professor W. J. Lewis and Mr. A. Hutchinson for their kind help. They very kindly allowed me to make free use of any instruments and mineral specimens in the laboratory.

Communications from the Oxford Mineralogical Laboratory. No. XXVII.

On Childrenite from Crinnis mine, Cornwall, and Eosphorite from Poland, Maine.

By Julien Drugman, M.Sc., F.C.S.

[Read June 16, 1914.]

UP to the present time only one of the several childrenite occurrences known has been examined both chemically and crystallographically. This is the well-known occurrence at the George and Charlotte mine near Tavistock, from which nearly all the specimens seen in collections were obtained. The crystals often attain a dimension of 1 cm., so that material for analysis can be easily obtained free from gangue. Crystals from this locality were analysed by Rammelsberg,[1] Church,[2] and Penfield,[3] and it is on the results obtained by the last-named that the comparatively simple formula for this mineral is based. A crystallographic examination by Brush and Dana[4] of eosphorite, a new manganese alumino-phosphate from Branchville, Connecticut, brought out a striking similarity to childrenite, and led them to suggest the chemical comparison of the two minerals. This was undertaken by Penfield, who showed, first of all, that the formula of eosphorite was a comparatively simple one, viz. $2(Mn,Fe)(OH)_2 . Al_2O_3 . P_2O_5 . 2H_2O$; secondly, that by using carefully picked childrenite, its formula is proved to be identical with that of eosphorite, childrenite having mainly iron as its divalent metal, while in eosphorite manganese predominates. The older analyses of childrenite

[1] C. F. Rammelsberg, Ann. Phys. Chem. (Poggendorff), 1852, vol. lxxxv, p. 435.

[2] A. H. Church, Journ. Chem. Soc., 1873, vol. xxvi, p. 103.

[3] S. L. Penfield, Amer. Journ. Sci., 1880, ser. 3, vol. xix, p. 315.

[4] G. J. Brush and E. S. Dana, Amer. Journ. Sci., 1878, ser. 3, vol. xvi, p. 35.

by Rammelsberg and Church, on the other hand, did not agree with each other, and led to much more complex formulae.

Besides the George and Charlotte occurrence of childrenite, some others are known, viz. Wheal Crebor, also near Tavistock; the Crinnis mine near St. Austell, Cornwall; Hebron, Maine, U.S.A.; and finally in the granite of Greifenstein near Ehrenfriedersdorf in Saxony. None of these occurrences have been investigated chemically, although the probability of the existence of gradations between the ferriferous childrenite and the manganiferous eosphorite would render such investigation of interest.

The Oxford Mineralogical Department having a large number of specimens of the Crinnis occurrence, Prof. Bowman suggested to me their more detailed study, and while I was still engaged in this work, a lucky chance brought into my hands a hitherto undescribed find of eosphorite from a new American locality, namely, Poland, Maine. I have to thank Prof. Palache of Harvard University for entrusting me with this material, which he had already recognized as eosphorite. It was part of the very large store of valuable, and often unique, mineralogical material awaiting detailed study in the Holden Collection,[1] lately bequeathed in its entirety to Harvard University. Besides eosphorite, several more of the rare Branchville phosphate minerals are present on these specimens, but these will not be dealt with in this paper, the object of which is to compare childrenite and eosphorite.

Childrenite from the Crinnis mine, Cornwall.

The mineral occurs as minute (rarely reaching 1 mm.) but distinct crystals on the surface of the walls of narrow cracks in killas, sometimes on quartz, and is almost always coated with a layer of hydrated ferric oxide, which colours it dark brown. The real colour is a very pale buff to almost colourless. The crystals on quartz are generally free from this coating, and these show bright, though much striated faces. The crystals adhere closely to the matrix, and their small size makes it difficult to obtain pure material for analysis by picking off the separate crystals, which was the method first attempted. The procedure found most useful was as follows: The crystals were gouged away from the killas with a strong, pointed dentist's chisel, the point of which was pushed well under the crystals, to prevent breaking them up too much. The loosened material was next sifted through a wide-meshed sieve, the

[1] See this volume, p. 117.

coarser killas flakes being left behind. The finer killas dust was next removed by rolling the powder down an inclined plane of moderately coarse paper. The childrenite grains roll down easily, whilst the flatter killas particles remain behind. Warm concentrated hydrochloric acid was next poured on to the material and washed away after a few minutes. This was repeated till all oxidized ferruginous matter had been dissolved away and the fresh acid remained colourless. As far as could be seen, childrenite is not acted on by the acid under these conditions, though eosphorite does not withstand the same treatment: it seems to become partially dehydrated and then to dissolve readily in hydrochloric acid. Quartz was next removed by suspension in a mixture of methylene iodide and toluene, and the remaining specks of impurities removed by hand-picking with a wet camel's-hair brush.

The usual methods were employed in the analyses; but in some of the analyses one modification was used which may be mentioned here. The phosphoric acid was precipitated by ammonium molybdate immediately after dissolving the ignited material in acid, and the analysis continued in presence of the molybdate. There seems, however, to be greater difficulty in completely precipitating the manganese by bromine, but otherwise the method seems quite serviceable if each precipitation is repeated before weighing. The analyses (I–V) show slight variations, due to the fact that different samples of material were used. The mean results (VI) agree well with Penfield's analyses of childrenite from the George and Charlotte mine, which are quoted under VII and VIII for comparison. The mineral from Crinnis mine, however, contains rather more iron and correspondingly less manganese.

	Crinnis mine.						George and Charlotte mine (Penfield).	
	I.	II.	III.	IV.	V.	VI. (Mean)	VII.	VIII.
P_2O_5 ...	29·83	—	—	—	29·80	29·80	30·19	29·98
Al_2O_3 ...	21·09	—	—	—	21·34	21·20	21·17	21·44
FeO ...	28·41	27·96	28·03	28·55	28·60	28·30	26·54	26·20
MnO ...	2·94[1]	3·58	—	3·35	3·26	3·35	4·87	—
CaO ...	0·97	0·98	—	1·08	0·61	0·90	1·21	—
Na_2O ...	0·25	—	—	—	—	0·25	—	—
H_2O ...	15·31	15·28	15·41	15·24	—	15·30	15·87	—
Insoluble ...	1·03	0·92	1·06	—	0·88	0·95	0·10	—
	99·83					100·05	99·95	

[1] There was some loss of manganese in this analysis.

The crystals are not suitable for accurate measurement, the faces being invariably striated or rounded and complicated by vicinal forms. A few measurements of the interfacial angles are given below for comparison

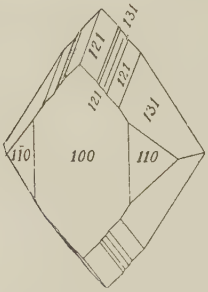

Fig. 1.—Crystal of Childrenite from Crinnis mine, Cornwall.

with those of Miller for the George and Charlotte crystals. Two crystals of the latter occurrence were also measured, and the results are given below:—

Angle.	Crinnis mine.			George and Charlotte mine.		
	Crystal No. 1.	No. 2.	No. 3.	Miller.	No. 1 (J. D.).	No. 2 (J. D.).
(121) : ($\bar{1}$21)	49° 39′, 32, 30	49° 29′, 29	49° 49′, 29, 28, 41	49°56½′	49° 35′	49° 37′
(121) : ($1\bar{2}1$)	81° 38′, 46, 47, 58	...	...	82° 7½′	82° 4′	81° 51′, 50, 50, 54
(110) : ($1\bar{1}0$)	...	75° 31′	...	75°46′	76° 1′, 2, 3, 2	75° 33′, 43, 44

The results, as may be seen, are not sufficiently reliable to enable one to calculate the elements with any accuracy. It was therefore considered unnecessary to carry out detailed optical measurements of this material, especially as the preparation of accurately orientated prisms from such small crystals would have presented great difficulties. Such measurements would have been of value if one could have been certain that the material was quite homogeneous. Analyses and measurements

tend to show, however, that the material is not homogeneous, and Des Cloizeaux's observation that the axial angle is variable confirms this. The comparatively large tabular or prismatic crystals from Hebron, Maine, might prove valuable material for completing our knowledge of the isomorphous childrenite-eosphorite series.

The author has been able to procure several well-crystallized specimens of the Greifenstein occurrence, which will probably also be useful for chemical and crystallographic investigation, though not for optical examination. The form (120) was observed on several crystals of one specimen, otherwise the habit is similar to that of the specimens from Cornwall and Devon; (121) is the best-developed form, and is generally accompanied by (110) and (100). The forms (111) and (131) were not observed, except as narrow strips on some of the more striated crystals. The large crystals, up to $1\frac{1}{2}$ cm. in width, show unstriated though superficially rough (121) faces. This occurrence differs from the British ones chiefly in that the mineral forms more or less indefinite nodules or large rough crystals in the cavities of the pegmatitic granite, instead of being found as small distinct crystals coating the walls of a fissure.

It may be useful, in this place, to draw attention to certain inaccuracies which have crept into the literature concerning childrenite. The mineral was first described by H. J. Brooke[1] in 1823, and named by him after J. G. Children, of the British Museum. Several subsequent publications gave the correct reference to his original description, but Allan,[2] in 1834, states that Lévy was the discoverer and namer of the species. I have, however, been unable to find any record of a description of this mineral by Lévy before 1837,[3] when he published further details about childrenite with new drawings, but this makes no claim to be a first description of the mineral. From this time onwards the error has been perpetuated in several works, including the standard treatise on mineralogy, Dana's 'System', the sixth edition (1892) giving the correct reference to Brooke's original article, but erroneously under Lévy's name. The mistake is, I think, traceable to a short note in Berzelius's 'Jahres-Bericht' (1825, vol. iv, pp. 149 and 150). Here a number of new minerals are described, and the paragraph which mentions Brooke's discovery of childrenite begins rather ambiguously and follows imme-

[1] H. J. Brooke, Quart. Journ. Sci. Lit. and Arts (Roy. Inst. Great Britain), 1823, vol. xvi, pp. 274–275; sometimes called Brande's Journal.

[2] R. Allan, 'Manual of Mineralogy.' Edinburgh, 1834, p. 39.

[3] A. Lévy, 'Description d'une collection de minéraux formée par M. H. Heuland . . .' London, 1837, vol. iii, pp. 409–410, and Plate 81, fig. 2.

diately on a paragraph describing some new minerals of Lévy's. The first part of the paragraph may be quoted :—'Brooke fährt fort, die Mineralogie bisweilen mit neuen Mineralien, aber oft und in Menge mit neuen Namen zu bereichern ; solche sind : Cleavelandit, Arfvedsonit, Latrobit, Childrenit, Sommervillit. Man darf jedoch nicht glauben, dass diese alle neue Verbindungen bezeichnen.' This ambiguous note immediately following a paragraph with Lévy's name is the probable origin of the error ; this impression becoming strengthened by Lévy's publication of new drawings and descriptions.

The statement is made in a number of publications that childrenite also occurs in Cumberland, though no description of such an occurrence has ever been published. This statement rests on an error which appears in Rammelsberg's chemical investigation of childrenite.[1] He begins thus : 'Zu den seltensten und in chemischer Beziehung fast ganz ungekannten krystallisirten Mineralien gehört der Childrenit, welcher auf einem Gang der George- und Charlotte-Grube bei Tavistock in Devonshire, begleitet von Spatheisenstein, Quarz und Kupferkies vorkommt, und nur noch bei *Callington in Cumberland* sich gefunden haben soll.' Cumberland as a childrenite locality should therefore be struck out, for Callington is in Cornwall. The locality referred to is probably the George and Charlotte mine itself, or one of the other occurrences near Tavistock, which are also near to Callington over the Cornwall-Devonshire boundary.

It may be well also to draw attention here to the second volume of V. Goldschmidt's 'Atlas der Krystallformen' (Heidelberg, 1913), in which the collected drawings and list of references to childrenite have much facilitated my search after childrenite literature. The following minor slips in the text-volume may be corrected :—

On p. 136, in the 'Bemerkung', line 3, for '(unsere Fig. 9)', read '(unsere Fig. 8)'.

On p. 137, following Fig. 1, for 'Brandes' read 'Brooke'.

On p. 137, following Fig. 4, for 'Taf. 76, Fig. 480', read 'Taf. 76, Fig. 460'.

In Goldschmidt's 'Atlas' the original drawings are exactly reproduced, so that most of the crystals of childrenite appear in the old setting, in which the pseudo-hexagonal character of the vertical axis (now *b*-axis) is made plain. The distinctly prismatic character of some childrenite crystals, and more especially of those of eosphorite, led Brush and Dana to a change in setting, in which this direction of elongation becomes the

[1] C. F. Rammelsberg, loc. cit.

vertical axis, and the *c*-axis of most of the older drawings becomes the *b*-axis. The last three drawings in the 'Atlas', one of which is of an eosphorite crystal, are given in this new setting, which seems to me well entitled to supersede the older ones.

Eosphorite from Poland, Maine, U.S.A.

The material examined is from the Holden Collection, now in the Harvard Mineralogical Museum, and it came from A. R. Berry's quarry at Poland, Maine. The matrix on which the eosphorite occurs consists largely of rhodochrosite, often well crystallized in dog-tooth forms, mixed with a black oxidized manganese compound. This latter generally coats the eosphorite prisms, but can readily be flaked away with the help of a small, pointed chisel, exposing the bright surfaces of the eosphorite undamaged. The eosphorite forms small, roughly radiated aggregates of prismatic crystals, some of which have very sharp end-faces giving excellent readings on the goniometer. The colour is a pale pink, and both crystal measurements and analyses show this eosphorite to be very similar to the Branchville occurrence described by Brush and Dana and analysed by Penfield. It approaches, however, more closely to the ideal iron-free eosphorite, having appreciably less iron than the original mineral from Branchville.

The analyses are given in the table below (Nos. I–III) with those of Penfield (IV and V) and Wells (VI). In No. I a certain amount of rhodochrosite was noticed after ignition, but was readily removed, allowance being made for its loss of weight on ignition. This was determined on a separate sample of pure rhodochrosite. In No. III some of the eosphorite was somewhat opaque, having probably already suffered slight dehydration; hence the rather high result for its alumina and lower water percentage. Otherwise this sample was very pure. No. II contained a small proportion of rhodochrosite, in grains too small to be removed after ignition; hence, probably, the higher manganese and lower phosphoric acid percentages.

	Poland, Maine.			Branchville, Connecticut.		
	I.	II.	III.	IV.	V.	VI.
P_2O_5 ...	31·31	30·71	...	31·05	31·43	31·39
Al_2O_3 ...	...	...	22·23	22·19	21·03	21·34
FeO ...	5·55	4·74	...	7·10	6·84	6·62
MnO ...	25·79	26·26	...	23·51	22·43	22·92
CaO ...	0·81	...	...	0·54	3·01	1·48
Na_2O ...	...	...	...	0·32	...	...
H_2O ...	15·46	15·59	14·75	15·60	15·07	15·28
Insoluble ...	...	...	...	...	...	1·46
				100·31	99·81	100·49

Six of the terminated crystals were measured and gave concordant results. These are probably sufficiently accurate to serve for a re-calculation of the elements; the hitherto accepted values having been obtained from the measurement of a single crystal. The faces observed were (111), (121), (110), (010), (100), with some less definite vicinal faces in the prism-zone. Prof. Palache mentions one good (320) face observed by him. The cleavage parallel to *a* (100) mentioned by Brush and Dana was not confirmed on these crystals. There is marked elongation parallel to the *c*-axis, and so far no doubly-terminated crystals have been observed. Fig. 2 shows the habit, which is very similar to that of the Branchville crystals.

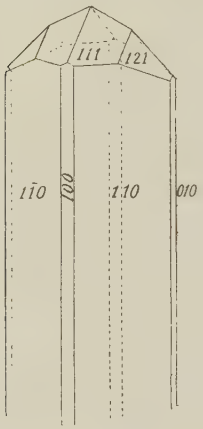

FIG. 2.—Crystal of Eosphorite from Poland, Maine.

Angle.	No. of observations.	Poland, Maine.		Branchville (Brush and Dana).	
		Observed.	Calculated.	Observed.	Calculated.
(010) : (110)	11	$52°19'^{+4'}_{-2}$	*	52°12′	52°10′
(111) : (1̄11)	6	$61\ 8\pm1$	*	61 2	*
(010) : (121)	15	$49\ 28^{+3}_{-1}$	49°30′	...	...
(121) : (111)	6	$17\ 20^{+3}_{-1}$	17 22·5	17 18	17 25
(100) : (111)	10	$59\ 26{\cdot}5\pm0{\cdot}5$	59 26	...	...
(100) : (121)	6	$65\ 8^{+11}_{-5}$	65 8	...	...
(121) : (1̄21)	7	$49\ 41^{+5}_{-2}$	49 44	49 39	49 34
(110) : (111)	6	$50\ 0^{+3}_{-6}$	50 1	49 55	49 59
(111) : (1̄11)	2	$80\ 0+1$	79 58	80 0	80 2
(121) : (1̄21)	5	$101\ 24^{+4}_{-9}$	101 22	...	...
(010) : (320)[1]	1	62 55	62 45	...	...
(110) : (1̄10)	...	...	75 22	75 36	75 41
(111) : (1̄11)	...	...	46 15	46 28	*

[1] Communicated by C. Palache.

The calculated axial ratios are :—

$a : b : c = 0{\cdot}7724 : 1 : 0{\cdot}5126$ (Poland, Maine).

(Brush and Dana) $0{\cdot}7768 : 1 : 0{\cdot}5150$ (Branchville).

Brush and Dana's results would approach the new measurements much more closely if they had not chosen the angle $(111) : (1\bar{1}1)$ of 46° 28′ as one of their fundamental angles. This is the one showing the maximum divergence when compared with the new measurements, the actual differences being only about 5′ in the extreme cases for all the other angles. Measurements of a greater number of crystals of childrenite would probably also bring the parameters of that mineral nearer to those of eosphorite. Unfortunately, childrenite appears to be formed under less favourable conditions than eosphorite, and striated and vicinal faces are the rule.

The plane of the optic axes is a (100) and the acute bisectrix is normal to b (010). A prism cut from a crystal of eosphorite from Poland, Maine, with its refracting edge parallel to c (001) and its refracting angle bisected by the axis a accurately to 4–5′, gave the following values for the greatest and least indices of refraction; and a plate cut parallel to b (010) gave the following value for the optic axial angle :—

λ in μμ	α	γ	2E
567 (Tl)	1·6438	1·6706	66° 37′
589 (Na)	1·6420	1·6691	65 27
671 (Li)	1·6386	1·6643	62 48

A more detailed comparison of the childrenite-eosphorite isomorphous series will only be of real interest when the pure end-members of the series are available in sufficiently perfect crystals for all their properties, chemical, geometrical, and optical, to be determined. A full examination of the other material already known, i. e. that from Hebron and that from Greifenstein, should, however, be carried out.

I wish to thank Professor H. L. Bowman for his friendly advice during the course of the work described here.

Mineralogical Department, University Museum, Oxford.

Note on the colours of some alluvial Diamonds.

By F. P. Mennell, F.G.S., M.I.M.M.

[Read January 26, 1915.]

IN 1906 the present writer gave a brief account[1] of the interesting alluvial diamond field which is situated on the borders of the Somabula Forest in Southern Rhodesia. The area is not of very great economic importance, but it has nevertheless yielded to date about 10,500 carats of diamonds (valued at over £45,000). These are extracted from thick beds of gravel which, as described in the paper referred to, generally consist of well-rounded pebbles in a matrix of sandy clay.

The diamonds themselves are almost invariably of a green shade in the rough state, though it may be as well to mention, before going on farther, that this colour is entirely lost[2] in the course of the usual process of cutting and polishing to fit them for use in jewellery. The writer did not at first attach any particular significance to this last fact, or indeed to the colour itself, except as a peculiar characteristic of the locality. When, however, a rather rich patch of gravel was opened up which yielded some forty or fifty colourless or almost colourless stones and no strongly coloured ones at all, the question was rendered of greater interest. It was evident that whatever sorting process had been at work during the deposition of the diamonds among the other constituents of the gravel, colour could not have been the determining factor in their distribution. Moreover, when another section of the workings was entered upon a certain number of yellowish and brownish stones were found. A little consideration showed that there seemed to be a definite relation between the colour of the diamonds and the character of the matrix in which they were embedded, and this idea gained considerable confirmation from the fact that several diggers at work on the Ngamo section of the gravels, some ten miles away from the main Somabula workings, independently volunteered a similar statement about the area in which they were at work.

[1] F. P. Mennell, Geol. Mag., 1906, pp. 459–462.

[2] The colours when cut are those known as 'blue-white', 'Cape-white', &c.

The ordinary run of stones come from gravel in which the matrix is a sandy clay containing a very small amount of iron oxides, and their colour, which ranges from a mere tinge of green to a dirty deep green like that of an ordinary beer-bottle, would seem to be due to the impregnation of a thin surface layer of the crystals by ferrous salts. The uncoloured diamonds came from a working in which the finer material of the gravel consisted almost entirely of a very pure clay, nearly white in colour, and capped by a seam or 'false bottom' of pinkish clay, which would obviously tend to prevent any downward percolation of iron-bearing solutions. The yellowish and brownish stones were not found until the extraction of a certain amount of gravel strongly impregnated with iron oxides and sometimes assuming an almost lateritic character. Some of the stones (both brown and green) that were examined[1] showed cracks, and along these, as might have been expected, the colouring matter had obviously permeated to a much greater extent than elsewhere, so much so as to give them the appearance of being spotted with small inclusions.

It may be emphasized here that although the colour is entirely lost during cutting operations, which involve the complete removal of the natural surface of the stones, it is certainly not due to a mere coating or incrustation upon them. No effect is produced on the rough stones by the prolonged immersion in hydrofluoric acid to which they are subjected for cleaning purposes. Moreover, during some experiments in mechanical separation by means of a fused mixture of potassium and lead nitrates the colour also remained quite unaffected, although fears were originally entertained that the stones might be completely destroyed.

The permeation of colouring matter even for a very small distance into such a hard and compact substance as the diamond may perhaps seem almost incredible, and it may further be objected to the suggestion here put forward, that the diamonds from the Vaal river and other South African alluvial diggings seldom or never show any similar coloration. This is a fact which must certainly be faced, though it may be pointed out that the Somabula gravels are undoubtedly much older than even the high-level gravels of the Vaal, as they are quite unconnected with any present-day river system. The length of time which the diamonds have lain in the gravels may well be an important factor in the problem. It is very interesting in this connexion that the diamonds which have several times been recorded from the ancient (Archaean)

[1] All the diamonds extracted during several years' work on the field were seen by the writer.

conglomerates known popularly as 'banket', both at Johannesburg and near Klerksdorp in the Transvaal, were all green in colour. I have personally seen several specimens and can testify to their close resemblance to the darker Somabula stones. They differ, however, in the very important respect that they remain of a fine green shade when cut. The time factor may well therefore come into play.

Though green stones are extremely rare in the other South African alluvial deposits, such a colour is not unknown either in India or in Brazil. In the former country such stones are known as 'banspat' or bamboo-leaf' diamonds, and are very highly prized by the native princes and other wealthy persons. They are mounted and worn in the rough state owing to the loss of colour on cutting. In Brazil green stones are uncommon. They favour certain special localities as a rule[1] and are noteworthy owing to the fact that, though their colour is, as usual, superficial, they are, when cut, the finest stones known in the trade.

It is of interest to note that Sir William Crookes[2] has succeeded in colouring diamonds by means of radium. This colouring is also superficial, being due to the α-rays, which penetrate to the same extent as in the formation of a pleochroic halo in a mineral like mica.[3] It is unlikely that radio-active processes have any influence in colouring the stones already described, though I much regret that owing to the fact that I do not now possess any specimens, I have been unable to put the matter to the test of experiment.

In spite of all the objections which readily occur to one, it still seems at least a good working hypothesis that the coloration of the green diamonds found in alluvial deposits is due to infiltration from without (presumably of iron compounds) after the stones were deposited in the gravels where they are now found.[4]

I wish to record my acknowledgements to Messrs. Julius Pam and J. C. Mance for several items of information which have been of service in the preparation of this paper, and to Dr. G. T. Prior, F.R.S., for kindly permitting me to examine several specimens in the British Museum collections.

[1] See, for instance, F. H. Hatch, Proc. Cambridge Phil. Soc., 1913, vol. xvii, p. 63.

[2] Sir W. Crookes, Proc. Roy. Soc., London, 1904, vol. lxxiv, p. 47.

[3] Sir W. Crookes, Phil. Trans. Roy. Soc., 1914, ser. A, vol. ccxiv, p. 436.

[4] It is, of course, assumed that they were originally derived from ultrabasic rocks, as in all cases where they have been found *in situ*.

Note on the colour and alteration of Pyrrhotite.

By F. P. Mennell, F.G.S., M.I.M.M.

[Read January 26, 1915.]

THE colour of the well-known iron sulphide, pyrrhotite or pyrrhotine, is given in most treatises on mineralogy as 'bronze-yellow'. Dana calls it 'between bronze-yellow and copper-red', and also notes that it is 'subject to speedy tarnish'. The accuracy of the last statement will not be doubted by any one who has had much acquaintance with mining operations in districts where pyrrhotite is a common lode mineral, but it does not appear to have been put on record in any scientific publication that the characteristic colour, not very accurately designated 'bronze-yellow', does not seem to be the original one of the unaltered mineral.

The writer's attention was first drawn to this fact about twelve years ago, when curator of the museum at Bulawayo, by the receipt, from the Nelly mine in the Insiza district of Rhodesia, of a mineral for identification which was as nearly as possible tin-white in colour. As tests showed that it contained nothing but iron and sulphur, it was, after some hesitation, put down as pyrrhotite, and the correctness of this determination was borne out by the fact that some months later the specimen was found to have assumed the usual 'bronze-yellow' colour. A similar observation was made on numerous other occasions, and the writer drew the attention of Professor, now Sir Henry, Miers to the fact in 1904. Later on, when directly associated with mining operations, he made several attempts to ascertain how long the change of colour took to accomplish, using specimens which he had himself extracted from working faces in various mines. Precise results were not obtained, owing to long and frequent absences from head-quarters on every occasion when fresh specimens had been secured, but it is safe to say that a month is sufficient for a marked change of colour to take place, not only on the surface but throughout the whole mass of a small specimen.

The cause and nature of the change it is not proposed to discuss here, but it seems possible that the genesis of the mineral may have some

bearing on the subject. Experience seems to show that in all cases where it occurs, in Rhodesia at any rate, it is a mineral which was either originally formed under conditions of great heat and pressure, or afterwards subjected to such influences. The same appears to be the case with the only English occurrences of which the writer has personal knowledge, namely, those round the north of Dartmoor. The mineral lodes (usually worked for gold) in which it often occurs in Rhodesia are known to be older than the great granite masses which have invaded the country rocks. The pyrrhotite is only characteristic of lodes in the contact zone, and is evidently an original constituent of them, as indicated by the fact that it occurs in intimate association with other minerals which would show obvious signs of alteration if it had been deposited subsequently to them. For instance, at the Antelope mine, where both the lode and the neighbouring rocks are chiefly contact altered sediments very close to a great granite mass and actually penetrated by offshoots from the granite, pyrrhotite is found enclosed in perfectly fresh augite, biotite, &c. It appears very probable in this and other cases that the original sulphide was pyrites, and that during the progress of the metamorphism half the sulphur was driven off. All the secondary sulphides subsequently deposited along cracks and joint-planes are in the form of pyrites. The difference between the circumstances of heat and pressure attendant on the formation of pyrrhotite and those prevalent at the surface of the ground may have much to do with the curious colour-change which takes place after its extraction from deep down in a mine.

When damp, as is always the case in a mine, pyrrhotite decomposes with extraordinary rapidity on exposure to the atmosphere, and in gold ores which contain it, the rapid production of ferrous sulphate from this cause often prevents the use of the cyanide process on the raw ore, owing to absorption of oxygen and reprecipitation of the dissolved gold. The Antelope and Giant mines in Rhodesia may be instanced in this connexion. The 'drives' in the former are even coated with masses of glittering crystals and stalactites of iron sulphate, owing to the abundance of pyrrhotite in the lode.

The Garnets and streaky rocks of the English Lake District.

By J. Frederick N. Green, B.A., F.G.S.

[Read June 15, 1915.]

THERE exists in the Lake District a peculiar type of metamorphism of which no analogue has, as far as the writer is aware, been described elsewhere, with the exception, perhaps, of South America. It is indicated chiefly by the presence of garnets and 'streaks', the former being found indifferently in every variety of igneous rock of the district, the latter being mainly confined to the rhyolites or quartz-keratophyres. The most similar known to the writer is at Oyacachi in Ecuador, whence vom Rath [1] has described flow-brecciated soda-rhyolites which sometimes contain red garnets. He also refers to rocks which may be 'streaky'.

The presence of garnets in the Lake District volcanic rocks has long been known. Otley [2] recorded several localities. J. C. Ward [3] frequently referred to them, and regarded them as undoubtedly metamorphic. Sorby,[4] however, considered them original, but, later, W. M. Hutchings [5] suggested a secondary origin for minute garnets which he found in the Lake District slates. Dr. Marr [6] supported Sorby's view. But in the discussion on a posthumous (and unfinished) paper by E. E. Walker,[7] who, though not very definitely, suggested originality, Mr. Harker expressed the opinion that the garnets were of metamorphic derivation. The 'streaks' were noted by Ward,[8] who supposed them to be relics of

[1] G. vom Rath, Zeits. Deutsch. Geol. Gesell., 1875, vol. xxvii, pp. 341–342.

[2] J. Otley, 'A concise description of the English Lakes.' 6th edit., 1837.

[3] J. C. Ward, Quart. Journ. Geol. Soc., 1875, vol. xxxi, p. 599.

[4] H. C. Sorby, ibid., 1880, vol. xxxvi, Proc., p. 75.

[5] W. M. Hutchings, Geol. Mag., 1892, p. 154; see also Quart. Journ. Geol. Soc., 1904, vol. lx, p. 105.

[6] J. E. Marr, Proc. Geol. Assoc., 1900, vol. xvi, p. 476.

[7] E. E. Walker, Quart. Journ. Geol. Soc., 1904, vol. lx, p. 70, discussion on p. 105.

[8] J. C. Ward, loc. cit., pp. 411–413.

bedding. He noticed the resemblance of the rocks to the Welsh felstones, and concluded that they were altered felsitic ashes. Dr. Marr seems first to have noticed the close association between the streaky and the garnetiferous rocks, and to have separated them off as a definite group. Walker, in the incomplete paper already referred to, came to the conclusion that there was a streaky garnetiferous series of contemporaneous igneous rocks; and Dr. Marr[1] in 1906, accepting this view, named it the Sty Head Group.

The investigation of these rocks by the writer has chiefly been carried out in the neighbourhood of Haweswater, though they have also been examined near the Duddon River and about Borrowdale; and, with the kind assistance of Mr. A. Harker, use has been made of the fine set of specimens collected by Walker and preserved in the Sedgwick Museum at Cambridge. In a paper recently read before the Geologists' Association[2] it was shown that the Sty Head Group had no real existence in the Haweswater area, but that it is made up of infolds of the rhyolitic lavas at the top of the Borrowdales with portions of neighbouring andesite and tuff; and less detailed observations about Borrowdale, Seathwaite, and Thirlmere tend to the same conclusion for other parts of the Lake District.

The distribution of the garnets is curiously capricious. Over considerable areas of the Borrowdale Volcanics they are quite unknown. For example, the district between Cawdale and Ullswater, the Duddon Estuary (where, however, one garnet, 1·5 mm. in diameter, was found in a pumice-tuff of the Harrath horizon near Arnaby), the south-eastern section between Grasmere and Shap, and Eycott Hill. In other places, as about Rosthwaite and on Kidsty Pike, they are fairly plentiful in several types of rock. They are known in soda-rhyolites and andesites, both effusive and intrusive, hypersthene-basalts, andesitic slates, rhyolitic pumice-tuff, coarse rhyolite-variolite tuff, quartz-porphyry, granophyre, mica-porphyrite, and granite. In all these rocks the garnets are usually associated with pyrites, the presence of which is a good indication of the probable occurrence of garnets. Stratigraphically, they have been observed in every horizon of the Borrowdale Series except the Mottled Tuffs;[3] and also in andesites between the Mottled Tuffs and the Middle

[1] J. E. Marr, Quart. Journ. Geol. Soc., 1906, vol. lxii, Presidential address.

[2] J. F. N. Green, Proc. Geol. Assoc., 1915, vol. xxvi, pp. 195–223.

[3] For these horizons, see J. F. N. Green, 'The Older Palaeozoic succession of the Duddon Estuary.' [London (Dulau & Co.), 1913.]

Tuffs; between the Middle Tuffs and the Harrath Tuffs; and between the Harrath Tuffs and the Rhyolites.

This sporadic distribution is equally well marked on a smaller scale. On Kidsty Pike the Rhyolites and Upper Andesites are garnetiferous; tracing the same horizons to Measand Beck, Haweswater, they are found to contain none. On a still less scale the discontinuity is even more striking. The same band of rock—the same flow-line even—is found to be full of garnets at one point, and a few yards away to contain none whatever. Hand specimens may be selected, one end of which is crowded with garnets, while the other shows none.

The same patchiness characterizes the 'streaks', though the changes are not so rapid. Streaky rhyolites frequently pass into ordinary varieties, both laterally and vertically.

It is hardly possible that the rhyolites, augite-andesites, basalts, and quartz-porphyries of the Lake District could all have developed almandines in this capricious manner by crystallization from the original magma; and it is therefore necessary to look for subsequent alteration for their causation.

It will be convenient to begin the discussion of the mode of alteration by a description of the garnets. They are often of irregular form when minute, but if larger than a millimetre in diameter are commonly good rhombic-dodecahedra, sometimes with small faces of the icositetrahedron added. Crystals 5 mm. in diameter are frequent and they have been noted twice that size. All have the deep claret-red colour of almandine, and the uniformity in depth of coloration points to some uniformity in composition.

No quantitative analysis appears to be on record. By the kindness of Mr. G. T. Holloway, to whom I am greatly indebted, such an analysis is now available. The garnets used come from a basic andesite forming the upper part of the Upper Andesites in Riggindale, on the slopes of Kidsty Pike.[1] It would appear from this analysis that the garnets are fairly pure almandine. Mr. Holloway writes:—

'The sample consisted of two lots of garnets which had been almost completely separated from the matrix. One lot weighed 20 grams and was composed of whole and broken, transparent to opaque red garnets resembling ordinary almandine, and from about ¼ inch to about 1/20 inch in size. The other lot weighed 7 grams and consisted of similar material, but smaller and

[1] The exact spot is in the middle of a bare rock-face, easily identifiable by sloping flow-lines, at a point 400 yards north of the folds.

less free from waste matter. The garnets were from about 1/20 inch to about 1/30 inch in diameter.

In each lot, the waste consisted mainly of films or adherent pieces of greyish-green rock matter. No titaniferous iron-ore was found. The garnets were slightly magnetic, i. e. were attracted only by a powerful electro-magnet.

An analysis on picked garnets (free from waste matter) from the coarser lot, gave the following results on the material dried at about 105° C. :—

Silica	35·90
Ferric oxide	6·12
Ferrous oxide	27·48
Alumina	20·20
Manganese oxide	3·84
Lime	1·42
Magnesia...	3·28
Titanic acid	1·53
Alkalis, &c., and loss	0·23
	100·00

The alumina result is the lowest of three determinations. As is usual in alumina determinations, it is probably slightly high, so that the figure given for alkalis, &c., is likely to be slightly lower than is correct.'

To account for the production of these garnets, it is natural first to suggest contact-alteration. The evidence is, however, opposed to such a view. When ordinary non-calcareous sediments undergo purely thermal alteration, garnet seems always to require a higher temperature than either the production of biotite or the re-crystallization of felspar. This is particularly evident in the enormous zones described by Mr. Barrow in the Highlands of Scotland. In igneous rocks the same rule may hold, except perhaps in the case of lavas quite fresh when heated, but the evidence is not so full. Only one garnet is recorded in the lavas near the Shap granite, and that in a vesicle. The Eskdale granite aureole appears only to contain them in the neighbourhood of garnetiferous rocks not otherwise metamorphosed. They are not recorded among the varied igneous rocks thermally altered in Skye. In the chief garnetiferous areas of the Lake District there is no intrusive mass to which the thermal production of garnets could reasonably be assigned; and the mineral is not accompanied by new biotite, re-crystallized felspar, or by the compact hornblende so common round the Eskdale granite. There cannot, then, have been any considerable rise of temperature.

Turning to dynamic action, lime-garnet is known as an element of 'saussurite', which has been ascribed to great pressure. But there is no evidence for strong dynamic action in the district. Crush-conglomerates and mylonites have not been met with (the supposed crush-rocks near

Haweswater are simply the basal or crustal flow-breccias of lavas);[1] garnetiferous intrusives are often hardly affected by cleavage; and where any crushing has taken place the garnets are themselves affected, a highly birefringent material of a sericitic appearance being produced. If isostatic pressure is invoked, it is difficult to understand how a pressure sufficient to produce large garnets could be so capriciously distributed. Further, dynamic alteration does not account for garnets with high iron content in rhyolites.

Garnets, however, are known, though rarely, which must have been formed at comparatively low temperature with the aid of circulating solutions, gaseous or liquid. The well-known occurrence of garnet and topaz in lithophyses of rhyolite at Nathrop, Colorado, is of this character.[2] C. H. Smyth[3] has recorded partial replacement of scapolite by garnet; Cornu[4] and Jeremejew[5] pseudomorphs of garnet after idocrase; Sustschinsky[6] after fassaite; Pelikan[7] after augite; Cathrein[8] after gehlenite. Garnet is also known replacing limestone.[9]

In none of these is the operation of a considerable degree of heat absolutely excluded, but it is otherwise with the description by Brögger of 'Umhüllungs- und Ausfüllungspseudomorphosen' of garnet and natrolite after sodalite.[10] An occurrence very similar to that just mentioned, but indicating even more clearly the comparatively low temperature of formation, has been described by Kretschmer[11] from the contact-zone of Gobitschau near Sternberg in Moravia. The garnets here are partly like almandine and partly like grossularia, and occur superimposed on natrolite as the latest product of hydrothermal activity.

Some positive evidence for the production of garnet by circulating solutions has been noted in the eastern Lake District, but the strongest witness is to be found among the series of specimens collected by the late E. E. Walker and deposited in the Sedgwick Museum at Cambridge.

[1] See J. F. N. Green, Proc. Geol. Assoc., 1915, vol. xxvi, plate 17, fig. A.
[2] Whitman Cross, Amer. Journ. Sci., 1886, ser. 3, vol. xxxi, p. 432.
[3] C. H. Smyth, Amer. Journ. Sci., 1897, ser. 4, vol. iv, p. 312.
[4] F. Cornu, Min. Petr. Mitt., 1905, vol. xxiv, p. 336.
[5] P. W. Jeremejew, Abstract in Zeits. Kryst. Min., 1899, vol. xxxi, p. 505.
[6] P. Sustschinsky, Zeits. Kryst. Min., 1903, vol. xxxvii, p. 68.
[7] A. Pelikan, Sitz.-Ber. Deutsch. Natur.-Med. Ver. f. Böhmen, 'Lotos', 1899, vol. xlvii (N. F. xix), p. 342.
[8] A. Cathrein, Min. Petr. Mitt., 1887, vol. viii, p. 412.
[9] W. Lindgren, quoting S. F. Emmons, Trans. Amer. Inst. Min. Eng., 1901, vol. xxx (for 1900), p. 611.
[10] W. C. Brögger, Zeits. Kryst. Min., 1890, vol. xvi, p. 165.
[11] F. Kretschmer, Centralblatt Min., 1907, p. 299.

The smaller isolated bits of garnet are often found inside felspars, either porphyritic or in tuffs. The next stage is illustrated by such a specimen as that in fig. 2, where the garnet has replaced the centres

Felspar aggregates in Lake District rocks.

Fig. 1.—Arthur's Pike, Ullswater. Fig. 2.—Eagle Crag, Langstrath (3824).
Fig. 3.—Base Brown, Seathwaite (3819). Fig. 4.—Esk Hause (3834).
[The numbers are those of slides in the Sedgwick Museum collection.]
Decomposition products of felspar and garnet are included with those minerals in the drawings.

only of the individual crystals of a felspar aggregate. The latter is clearly an early stage in the formation of one of the numerous 'felspar-rings' described by Walker. But these rings show no resemblance of

any kind to the kelyphite fringes or to the reaction borders[1] found round certain garnets elsewhere; on the contrary, they differ in no respect from the glomeroporphyritic felspars of the rest of the rock, which are often notably rounded in form, as in fig. 1, taken from a specimen collected some miles from the nearest recorded garnets; and the manner in which the garnet has worked its way along the centres of the components of the aggregate (no doubt owing to the higher basicity and consequent higher solubility of these centres) indicates that it is corroding pre-existing felspar, not the reverse. A further stage is illustrated by fig. 3, and also by Plate XIV, fig. 4, in Walker's paper.[2] The ring-like character of the unaltered felspar is seen in such a case as fig. 4, which also shows a portion of unreplaced felspar near the centre.

If on reaching the confines of the felspar, the alteration has any difficulty in attacking the surrounding matrix, a pseudomorph should result. This accounts for the case figured in Walker's Plate XIII, fig. 2. Here the rock is an acid granophyre with numerous phenocrysts of quartz and felspar set in a delicate micropegmatite matrix. The garnet appears to have had some difficulty in pushing into this matrix and accordingly garnet and isotropic 'viridite' have formed a pseudomorph after orthoclase, the outlines of which are well preserved.

But in the case of the lavas, the garnet seems to have had no difficulty in spreading into the groundmass, the composition of which probably differs little from that of felspar with a small admixture of magnetite. In such circumstances good crystal faces are usually exhibited by the part within the groundmass; and this may be due to the comparatively homogeneous character of this groundmass when compared to the felspar phenocrysts, which, besides the differences in physical properties in varying directions due to crystalline structure, show basicity decreasing from the centre, and twinning on several plans. All the larger garnets, however, whatever may be the material bounding them, and many of the smaller, show a tendency to good crystalline form. This tendency to perfect crystalline form is very striking in hand specimens from the eastern Lake District; as the garnets break out from the surrounding rock in beautiful rhombic-dodecahedra.

If, while growing, the garnet meets a phenocryst that is not easily decomposed, its growth will be arrested in that direction. Two of Walker's figures illustrate this point excellently. In Plate XIII, fig. 3, a garnet in the Armboth dyke shows good crystal faces except in the

[1] See T. H. Holland, Rec. Geol. Surv. India, 1896, vol. xxix, p. 21.

[2] E. E. Walker, loc. cit.

direction of two quartz phenocrysts, which are in contact with the garnet. The quartzes are the ordinary rudely rounded phenocrysts of the rock, and it is impossible to suppose with Walker that they are corroding the garnet. Still more striking is Plate XIII, fig. 1. The rock in this case is a porphyry with phenocrysts of felspar and biotite and glomero-porphyritic aggregates of felspar which enclose some of the biotite (and also apatite). The aggregate figured is partly replaced by garnet, and the progress of the change outwards from the centre has been arrested by the biotite crystals, which are consequently left at the bottom of 'embayments' in the contour of the garnet. (Compare the behaviour of the 'streaks' towards biotite.) Had the felspar and biotite been formed by alteration of the garnet, as Walker apparently believed, they would show some differences from the phenocrysts; but this is not the case.

Garnets, with peculiarities of distribution which recall those of the Lake District, occur near Bastogne in the Ardennes. The rocks show some contact-alteration, but the garnets have been ascribed by Miss Raisin,[1] following Professor Bonney,[2] to the action of hot springs. Another case of curiously sporadic distribution in slightly altered rocks is well known in the Isle of Man, and I have noted in one of the described Geological Survey slides (No. E2417) a garnet enclosing needles of blue schorl. This is suggestive, but the rocks are very different in character from those of the Lake District, and I hesitate to compare the two cases at present.

But there are two reasons against the suggested mode of formation which still require consideration. In the first place, the zoning and optical anomalies which have been considered diagnostic of pneumatolytic garnet are absent. It may, however, be observed (*a*) that such phenomena do not appear to have been described in almandines; and (*b*) that these Lake District pseudomorphs are hardly comparable with the garnets formed by pneumatolysis near large intrusions, such as those of the south-west of England.

Secondly, why have not similar cases been noted elsewhere? It is admitted that the Lake District rocks are of a highly exceptional type, and accordingly an exceptional causation may be postulated. It is suggested that this is to be found in hydrostatic pressure. Most garnets when fused break up into minerals of lower density, and it seems clear that high pressure is necessary for the production of the almandine

[1] C. A. Raisin, Quart. Journ. Geol. Soc., 1901, vol. lvii, p. 55.
[2] T. G. Bonney, Quart. Journ. Geol. Soc., 1890, vol. xlvi, p. 214.

molecule. Accordingly, the exceptional cause would be solfataric action under considerable pressure.

As early as 1875 J. C. Ward[1] referred the garnets in the tuffs (in which he included many rocks now known to be lavas) to the action of highly heated water connected with the formation of the Eskdale granite. Although the writer sees reason to regard the Eskdale granite as connected with the volcanic series,[2] the distribution of the garnets shows no particular relationship to that intrusion; though perhaps they have some preference for the neighbourhood of minor intrusions. The constant association of garnet and pyrites and the prevalence of pyrites in the garnetiferous districts suggest solfataric action.

Turning to the 'streaks', they are chiefly to be found in infolds of rhyolite. In the eastern area these consist of pale rocks, exhibiting in a manner which is irregular and discontinuous, but far more constant than the garnets, numerous dark parallel linear marks which, when best developed, contain macroscopic quartz or pyrites. These marks are sections of parallel lenses, the direction of which corresponds within the limits of observation with the bedding, and, in a general way, with the flow-surfaces.

The streaks are brought into relationship with the garnets, not only by their distribution, but by the occasional occurrence of the latter as a component of the former, which are in general obviously secondary infiltrations. In the following discussion I confine 'streaks' to such structures, and do not deal with the flow-structures[3] which have been included with them. Highly developed original flow-structures are found in parts of the Lake District, notably at the junction of rhyolite and andesite, where they often seem 'eutaxitic' in character. But these are not considered here.

In order to indicate the arrangement of these curious markings, I take as an example a hand-specimen from the Naddle Beck infold near Haweswater. The area of one face is 62 square cm. On this are about sixty well-marked streaks, at an average distance apart of 4 mm., and with an average length estimated at between 2 and 3 cm. Under a hand-lens most of the streaks show merely a discoloration; but in eleven there is a visible fissure including red-brown powdery stuff. In seven of these pyrites can be detected, and there are two nests of pyrites not clearly connected with streaks.

[1] J. C. Ward, Quart. Journ. Geol. Soc., 1875, vol. xxxi, p. 599.
[2] J. F. N. Green, Quart. Journ. Geol. Soc., 1909, vol. lxv, p. 79.
[3] See E. E. Walker, loc. cit., Plate XIV, fig. 2.

The streaks in this and in many other rocks in the area originate primarily as fine cracks, which, while preserving one general direction, are extremely irregular on a small scale, often puckered in appearance, and throwing off short branches. They are marked by red opaque matter. In a more advanced stage these cracks become veinlets with quartz, chlorite, calcite and other carbonates, sericite, epidote, pyrites, sometimes garnet, and various indefinable materials, while the rock edging the crack or veinlet shows a development of products with a chloritic or serpentinous appearance. When the cracks cut a felspar phenocryst, or a flow line, absolutely no displacement can be seen to take place along the crack.

There is a complete absence of crushing along the cracks. But where 'streaky' rocks have been sheared, it is plain that the streaks are older than the squeezing. An instance is afforded by the Cawdale infold of rhyolite south-east of Sealhole, where movement perpendicular to the streaks has displaced, contorted, and dragged them out. They are also seen in places to be folded in exactly the same way as neighbouring bedded or fluidal rocks, notably above Low Barn, Haweswater, where the axes are about N.E.–S.W., pitching S.W. Specimens from this locality show irregular garnet in the streaks, which have been contorted.

The form and character of the cracks show that they are not produced by shearing, but by a process of internal readjustment in the rock itself. The structure may therefore be connected with the perlitic tendency of rhyolites.

Iddings[1] has described a case where, owing to differences in texture, there have been formed in rhyolite 'a multitude of nearly horizontal ones [cracks] which follow the planes of flow through all their complexities'.

In the eastern Lake District rocks, the cracks are shown by their general agreement with the direction of dip to have been originally horizontal, and in many cases closely resemble flow lines, especially when, as in rocks behind Low Whelter Farm, Haweswater, they wind round enclosed fragments. But they certainly cut flow lines not infrequently. This does not preclude the possibility that the general direction of flow may have had a controlling influence. In specimens from Seathwaite and Oxendale, as well as some from the eastern area, epidote streaks coincide strictly with the flow-lines, and appear to have originated in the manner suggested by Iddings.

[1] J. P. Iddings, Seventh Ann. Rep. U.S. Geol. Surv. for 1885-6, 1888, p. 260.

While perlitic structures are not uncommon in both acid and basic fragments enclosed in the tuffs, they are very rare in the flows of the Borrowdale Series. It seems possible that the cracks were due to contraction during cooling, and that the absence of perlitic curvature was determined by the presence during internal readjustment of hydrostatic pressure. The frequent addition of pyrites suggests that the subsequent infiltration took place during the solfataric period of volcanic episode. This infiltration replaces the groundmass and felspars of the rhyolites, but does not attack the biotite, as may be seen in a specimen from Dufton Pike in which the mica projects into the streaks.

It may be noted here that Rutley[1] has proposed solfataric action to explain a peculiar alteration in rhyolites from Dufton Pike in the Cross Fell area. He notes a mesh-like alteration of felspar (which I have myself seen in streaky rhyolites from several parts of the Lake District proper) and pseudomorphs that may be after garnet.

The conclusion is that the garnets, pyrites, and streaky alteration have been formed by circulating solutions under high hydrostatic pressure, probably during the solfataric stage of the Borrowdale volcanic episode.

[1] F. Rutley, Quart. Journ. Geol. Soc., 1901, vol. lvii, p. 31.

Detrital Andalusite in Cretaceous and Eocene sands.

By G. M. Davies, B.Sc., F.G.S.

Scientific and Technical Department, Imperial Institute.

[Read June 15, 1915.]

SIX years ago, in a paper read before this Society,[1] Dr. Herbert H. Thomas drew attention to the relative abundance of andalusite in the Pliocene deposits of Cornwall, East Anglia, and Kent, and also in various glacial and recent sands. When that paper was written, the only recorded occurrence of unaltered detrital andalusite in sedimentary rocks of greater age than the Pliocene was that in the Middle Chalk of Beer in Devonshire.[2]

Dr. Thomas concluded : 'It therefore appears that andalusite has not survived as such in the Cretaceous and Lower Tertiary rocks of the London and Paris basins. In all the older British sediments that I have examined . . . no unaltered grain of this mineral has been detected.

'It is, therefore, highly probable that andalusite cannot remain in a sand without decomposition for more than a limited period, after which its place is taken by certain micaceous aggregates, such as are of frequent occurrence in the Triassic sandstones of the west of England.

'It may, I think, be taken for granted that the presence of unaltered andalusite in a glacial or recent sand means that much of the detritus has been furnished either directly by some metamorphic area, or indirectly by Tertiary sediments derived in part from similar or identical metamorphic masses.'

In 1912 I referred to the occurrence of unaltered detrital andalusite in several Eocene and Cretaceous sands,[3] and more recently Prof. J. W. Gregory announced that Mr. G. W. Tyrrell has found it in the Triassic St. Bees sandstone of Seascale in Cumberland.[4] As these records are in

[1] H. H. Thomas, Mineralogical Magazine, 1909, vol. xv, p. 241.

[2] W. F. Hume in 'Cretaceous Rocks of Britain.' Mem. Geol. Survey, 1903, vol. ii, p. 507.

[3] G. M. Davies, Quart. Journ. Geol. Soc., 1912, vol. lxviii, p. 249.

[4] J. W. Gregory, Geol. Mag., 1915, dec. 6, vol. ii, p. 148.

papers on other subjects than andalusite, and are therefore liable to be overlooked, it seemed advisable to bring before this Society evidence of the frequent occurrence of andalusite in sediments of greater antiquity than the Pliocene.

A series of microscopic slides, exhibited at the meeting, represents the heavy minerals from various Eocene and Cretaceous sands, in all of which andalusite occurs in pleochroic and unaltered grains. Cases in which the presence of colourless andalusite is suspected are not recorded here. The reddish tint is given by the fast ray, the slow ray giving a colourless effect or sometimes a transient suggestion of green due to eye-fatigue after observing the red. Inclusions are usually few, or absent altogether. Some of the grains are elongated parallel to the vibration-direction of the fast ray, and appear to be either prisms or prismatic cleavage fragments. More often, however, there is no trace of this cleavage. The grains are then irregular in outline, with an uneven surface, as though minute flakes had been battered off them. None of the grains are well rounded. In greatest length they range from 0·12 to 0·62 mm.

The localities from which the samples were obtained, and the associated heavy minerals, are as follows :—

In the Bagshot pebble beds, at Holden's Wood, Brentwood (Essex), andalusite occurs in comparative abundance in association with ilmenite, staurolite, tourmaline, zircon, rutile, kyanite, and sillimanite.

In the Blackheath Beds of Hayes Common (Kent) and Kennel Wood, Shirley (Surrey), a few grains of andalusite were obtained. The associated heavy minerals are ilmenite, tourmaline, staurolite, zircon, kyanite, rutile, garnet, and magnetite ; also epidote, hornblende, and apatite in the former sample, which is loamy, and green spinel in the latter.

A sample of the glauconitic loamy bottom bed of the Woolwich Beds from Plumstead (Kent) yielded andalusite, together with ilmenite, zircon, rutile, kyanite, tourmaline, staurolite, hornblende, magnetite, garnet, and spinel.

In the sandy Reading Beds of Northwood (Middlesex), and the Cowcroft outlier (Bucks), andalusite is associated with ilmenite, zircon, kyanite, tourmaline, staurolite, rutile, magnetite, sillimanite, and garnet.

In the Thanet Sand I have only observed one grain of pleochroic andalusite, though colourless grains in other samples may be this mineral. The grain in question was in a sample from Wansunt pit, Crayford (Kent).

In the Folkestone Beds andalusite was seen in four out of nine samples

examined. The samples containing it came from Reigate and Limpsfield (Surrey), and Dunton Green and Folkestone (Kent), and the associated heavy minerals are kyanite, tourmaline, staurolite, ilmenite, zircon, rutile, garnet, and magnetite, with spinel at Dunton Green, pyrite and barytes at Folkestone.

A sample of Lower Greensand sponge gravel from Faringdon (Berks) yielded andalusite, together with kyanite, zircon, ilmenite, rutile, staurolite, tourmaline, and garnet.

A sample of ferruginous sand of Wealden age from Shotover Hill (near Oxford) yielded andalusite associated with tourmaline, kyanite, zircon, rutile, staurolite, ilmenite, garnet, magnetite, and spinel.

It is evident from the above facts that andalusite is a frequent constituent throughout the Eocene and Cretaceous beds of the south-east of England. There is at least a possibility that it was derived from earlier sediments and not directly from metamorphic rocks. In some of the Pliocene and Pleistocene deposits it is more abundant than in any older beds that I have examined, but this is readily explained by the advent of detritus from fresh sources, Rhine-borne in the Pliocene beds of eastern England, and derived from the Cornish metamorphic areas in the case of the St. Erth Beds. It is unnecessary to assume excessive instability of the mineral, and also contrary to evidence in view of the freshness of the grains from Lower Cretaceous sands.

It thus appears that the presence of a small amount of andalusite cannot be regarded as evidence of the Pliocene or post-Pliocene age of the deposit in which it occurs or from which it was derived. Nor is abundant andalusite satisfactory proof of such comparatively recent age. Every petrologist who has examined many sediments has probably met with cases where a mineral, usually scarce in that deposit, becomes inexplicably abundant. It is, therefore, not improbable that andalusite may in some places occur abundantly in Eocene or older sediments.

On Bassetite and Uranospathite, new species hitherto classed as Autunite.

(*With Plate VIII.*)

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[Read June 15, 1915.]

THE name autunite was originally given to the well-known mineral from Autun, but it would seem that no crystals of this material have been found that would afford measurements on the goniometer. As the result of optical examination Des Cloizeaux (2) concluded that the mineral was biaxial, and he observed further that the angle decreased when the specimen was heated (6); the extinction was apparently straight, and he therefore referred the crystals to the rhombic system; with the contact goniometer he found $mm' = 90° 43'$. In the early part of last century some very beautiful crystals from Cornwall had been described and measured in England (4), and on crystallographic grounds were placed in the tetragonal system. The crystals occurred with torbernite, and the two minerals were not clearly distinguished by early writers (1). Des Cloizeaux assumed that the Autun mineral was identical with that from Cornwall, and he was indebted to Greg for an isolated specimen of the latter which afforded the measurements, published in 1858, on which the crystallography of the species has been based (3); he remarked, however, that the optic axial angle was greater than in the Autun mineral.

In 1879 Brezina (8) observed that small tabular crystals from Himmelsfürst mine in Saxony had an oblique extinction of 4°; their optical properties were much confused by twinning, and the faces were not good enough for goniometric measurement. In accordance with the optics, Brezina considered the mineral to be oblique; he measured the plane angles of the tabular basal plane (001), which now became the pinakoid (010), and found $\beta = 90° 30'$. The number of readings

obtained was not sufficient to give a reliable value for the ratio $a:c$, and the length of the b axis was, of course, unknown. Brezina therefore took Des Cloizeaux's measurements of the Cornish mineral, and retaining his fundamental angles, presented them as those of an oblique mineral with $\beta = 90° 30'$.

The data for autunite are thus of a somewhat composite character, and a further examination of the material seemed desirable. The description of various specimens hitherto classed together as autunite forms the subject of this paper[1]; it will be seen that the Cornish material here described falls into groups which are headed *A* and *B* respectively. The relationship between these substances and the Autun mineral will be discussed at the close of the paper, the name bassetite being proposed for *A* and uranospathite for *B*.

Mineral *A* (Bassetite).

Specimen No. 1.[2]

The locality of this specimen is not recorded, but comparison with other material makes it fairly certain that it is from Cornwall. The crystals occur in fan-like groups of almost parallel tables, in cavities of a black gossany material into which project spikes of black limonite. They are tabular on b (010) and almost square in outline, being bounded by poorly developed faces of forms $\{hk0\}$ and $\{0kl\}$; in many cases the corners are modified by bright faces of $\{111\}$ and $\{\bar{1}01\}$ (text-fig. 1). Twinning is frequent, so that two or more individuals oriented approximately at 90° are united on b. The measurements given below were obtained on projecting corners of simple individuals.

The interference-figure is biaxial with a wide angle, the negative acute bisectrix being perpendicular to b (010); this, coupled with angle of 90° measured from the face $(\bar{1}01)$ to b, supports the view that b is a plane of symmetry. The extinction is distinctly oblique and the crystals are therefore treated as belonging to the oblique system; there is no evidence of anorthic symmetry.

The almost square outline of the plane b (010), when bounded by the forms $\{hk0\}$ and $\{0kl\}$, indicates pseudo-rhombic symmetry; when $p(111)$ and $x(\bar{1}01)$ are present they modify the corners of b so that the outline is almost a regular octagon and the symmetry is then seen to be

[1] The author takes this opportunity of expressing his thanks to Dr. H. H. Thomas and Mr. W. F. P. McLintock for their advice in this work.

[2] No. L 1946, Museum of Practical Geology (Ludlam Collection).

pseudo-tetragonal. The deviations from true symmetry fall almost within the limits of error in reading, so that the angles β and $90°-\beta$ can only be separated with difficulty from a true angle of 90°. The oblique extinction fortunately affords a ready means of discrimination. Nineteen readings of the plane angle of the face *b* (i.e. the angle 100 : 001) showed that, with two doubtful exceptions, the axial plane lay within the acute angle between the axes *a* and *c*. The optical properties are thus consistent with the symmetry, and all the planes of the oblique crystal may be distinguished by their relation to the optic axial plane. The following measurements were made:—

External plane angles between the edges of the face *b* (010). (Measured under the microscope.)				Extinction angle on *b* (010) to the edge *bm*.	Goniometer readings.	
Edges.	*bm* : *bn*	*bm* : bp_1	*bn* : *bx*		bp_1 = (010) : (111)	*bx* = (010) : (10$\bar{1}$)
No. of readings	19	9	5	14	15	9
Highest	89° 50′	44° 40′	45° 45′	4° 0′	76° 55′	91° 4′
Lowest	89 9	44 0	45 20	2 42	74 8	89 12
Mean	89 30	44 23	45 29	3 17	75 38	90 5
Calculated	*	*	45 38	—	*	—

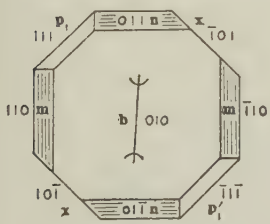
Oblique, $a : b : c = 0{\cdot}3615 : 1 : 0{\cdot}3662$; $\beta = 89° 30′$.

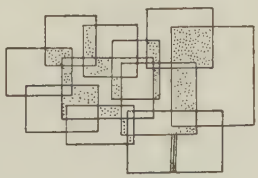
Forms: *b* {010}, p_1 {111}, *x* {10$\bar{1}$}, *m* {110}, *n* {011}, and undetermined {*hk*0} and {0*kl*}.

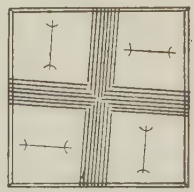
Cleavages: *b* perfect, *a* and *c* moderate.

Refractive indices (by the immersion method): $\gamma = 1{\cdot}580$, $\beta = 1{\cdot}574$.

Angle of extinction on *b* (010) with reference to the edge *bm*: 3° 17′.







Bassetite from Cornwall.

Fig. 1.—Simple crystal. Fig. 2.—'Chessboard' grouping of twinned and parallel crystals. Fig. 3.—Composite twin-crystal.

The measurements are not of high accuracy, but they possess interest

in that these crystals are intermediate in character between the scaly growths of specimen no. 2, and the stout crystals from Wheal Basset, described below. The latter differ in the presence of the form {121} instead of {111}, and the parameters assigned are not quite identical.

Specimen No. 2.[1]

This specimen, from Redruth, is typical of much Cornish material. The crystals are in cavities of a black gossan, forming flat groups composed of small square tables bounded by {*hk*0} and {0*kl*} (text-fig. 2 and Plate VIII, fig. 4). All the crystals lie in one plane, and the edges are approximately parallel; between crossed nicols, however, it can be seen that compensation frequently occurs between superposed lamellae, their axial planes being at right angles, so that the aggregate has a characteristic 'chessboard' appearance. The grouped crystals usually extinguish together with the exception of a few individuals whose extinction lies symmetrically on the other side of the edge.

The following determinations were made on these crystals: Extinction angle on *b* (010), with reference to the edge *bm*, 3° 49′. Refractive indices for sodium-light (determined by immersion in a mixed liquid), $a = 1{\cdot}580$, $\beta = 1{\cdot}574$, these values being identical with those obtained for the last specimen. Specific gravity (determined by the flotation method), 3·10.

Twinning.—Small tables can sometimes be isolated, which show very well-marked supplementary twinning (text-fig. 3). These plates are divided into four quadrants by rather broad bands which remain dark when the nicols are rotated; the extinction is approximately parallel in all four divisions, but the axial planes in adjoining sectors are at right angles, and the isotropic bands evidently arise from compensation between the overlapping portions of adjacent crystals. It is a remarkable feature that these dividing bands are by no means normal to the edges of the plate, though they are themselves at right angles; their orientation is most simply expressed by the statement that they are very nearly parallel with the extinction. The following approximate angles were measured on twins of this type, between the edge of the plate and the trace of the combination-plane: 85° 0′, 84° 35′, 85° 20′, 86° 20′, mean = 85° 19′. It is evident that the combination-plane is not a simple rational face. This question will be discussed further below.

Greg and Lettsom (4) remark that autunite was formerly obtained as

[1] No. L 1936, Museum of Practical Geology (Ludlam Collection).

bright yellow and nearly transparent crystals at South Wheal Basset, and that a specimen is in the British Museum; the measurements they publish were obtained from several small brilliant Cornish crystals, which exhibited the form {121} (oblique), a form also recorded by Des Cloizeaux. None of the specimens in the Museum of Practical Geology show this habit, but I am indebted to the Mineralogical Museum at Cambridge for facilities for measuring the very beautiful twinned crystal of this type which is described below; it will be observed that the results completely support the view that the symmetry is oblique, though the remarkable pseudosymmetry, coupled with twinning, will readily explain the earlier opinion that this substance was rhombic.

Specimen No. 3.[1]

The locality for this specimen is not recorded. It is a small isolated crystal about 1 mm. square and $\frac{1}{2}$ mm. thick; with the exception of two small planes at one corner, the back of the crystal is a cleavage plane, which does not yield good readings. Between crossed nicols it transmits light of higher orders, but is divided into halves by a

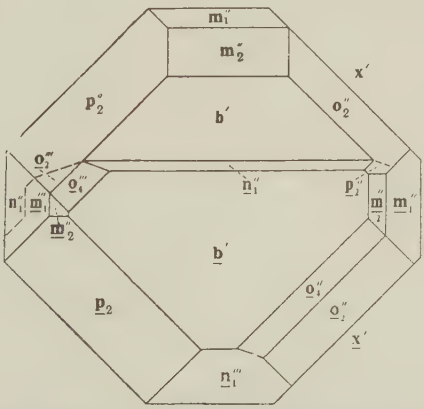


Fig. 4.—Twinned crystal of Bassetite. (For optical scheme see fig. 6.)

series of compensation bands which at once reveal the twinning. The faces give good readings, with a few exceptions, and the drawing (text-fig. 4) gives an almost exact representation of the appearance of the crystal.[2] The following table gives all the readings from both portions

[1] No. 1297, Mineralogical Museum, Cambridge (Brooke Collection).

[2] For convenience, the crystal is here viewed from the negative end of the *b*-axis.

of the twin. It was found that the measurements from the best faces were not suitable for direct calculation ; the parameters were therefore chosen so as to afford the best agreement between the observed and calculated angles.

Angle	bm_1	bm_2	bn_1	bo_2	bo_4	bp_2	bx
Readings observed	70° 34′ 70 40 70 54 70 24	55° 12′ 55 12 55 16 55 14	71° 21′ 70 56 70 50	63° 47′ 63 43	45° 23′ 45 26	64° 0′ 63 59 64 12 63 47	90° 13′ 89 57
Mean	70 38	55 13	70 53	63 45	45 24	63 59	90 5
Calculated	70 51	55 13	70 56	63 45	45 24	64 2	90 0

Angle	o_2m_1	o_2n_1	p_2m_1	p_2n_1	m_1x	m_2o_2	m_2p_2
Readings observed	42° 15′	42° 8′	41° 38′ 41 34 41 35 41 38	41° 37′	48° 25′ 48 30 48 42	39° 52′	39° 12′
Mean	42 15	42 8	41 36	41 37	48 32	39 52	39 12
Calculated	42 22	42 8	41 43	41 27	48 32	39 46	39 18

Oblique, $a : b : c = 0{\cdot}3473 : 1 : 0{\cdot}3456$; $\beta = 89° 17'$.

Forms : $b\{010\}$, $m_1\{110\}$, $m_2\{120\}$, $n_1\{011\}$, $o_2\{12\bar{1}\}$, $o_4\{14\bar{1}\}$, $p_2\{121\}$, $x\{10\bar{1}\}$.

It may be convenient in this place to give a table (p. 227) showing the symbols assigned to the respective forms by various authors, including the forms determined on the specimens here described. A stereographic projection of the forms as stated in the last column is given in text-fig. 5.

Optical properties.—By the prism method, through the faces $\underline{m}_2''$ and $\underline{m}_2'''$ the value 1·580 was obtained for the refractive index, but the reading was not very satisfactory ; this value accords with that obtained for specimens 1 and 2 above. Extinction-angle on b with reference to

the edge *bm* approximately 3°. The axial angle of crystals similar to these was determined by Des Cloizeaux, who found $2E = 110°$.

Greg (1858). Tetragonal.	Des Cloizeaux (1858). Rhombic.	Brezina (1879). Oblique.	A. F. H. Oblique.
P	*p*	*b* 010	*b* 010
	$a^{\frac{1}{2}}$	*m* 110	m_1 110
u			m_2 120
	$e^{\frac{1}{2}}$	*q* 011	n_1 011
			p_1 111
l	$b^{\frac{1}{2}}$	*p* 121	p_2 121
		π 12$\bar{1}$	o_2 12$\bar{1}$
			o_4 14$\bar{1}$
		(*a* 100)	(*a* 100)
		(*c* 001)	(*c* 001)
M	(*m*)	*d* 101	*x* 10$\bar{1}$

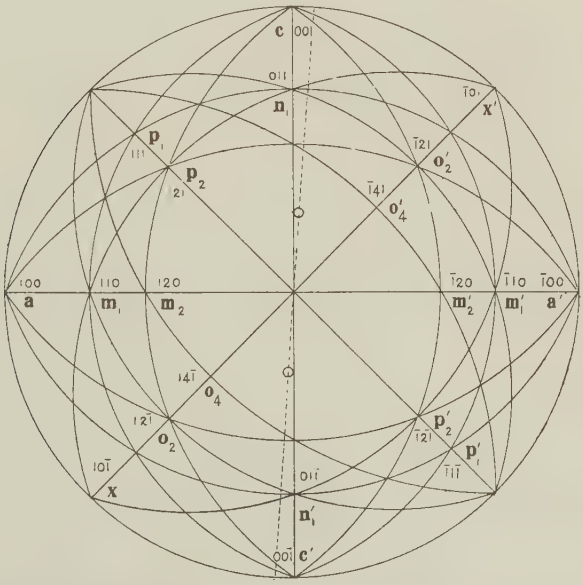


Fig. 5.—Stereographic projection of the crystal-forms of Bassetite.

Twin Law.—The relation between the two members is of special interest. Brauns (10) considered that the parallel extinction of some twins could only be explained by assuming parallel growth of the *a*-axis of one member with the *c*-axis of the other.

In the present crystal the faces b' and $\underline{b}'$ are parallel, while the faces $m_1''\ m_2''\ b'\ \underline{n}_1''\ \underline{b}'\ \underline{n}_1'''$ are in zone; the zone $[n_1''\ b']$, on the other hand, is inclined at about one degree to the zone $[\underline{m}_1'''\ \underline{m}_2'''\ \underline{b}'\ \underline{m}_2''\ \underline{m}_1'']$. The optical scheme (text-fig. 6) shows almost parallel extinction in the two members.

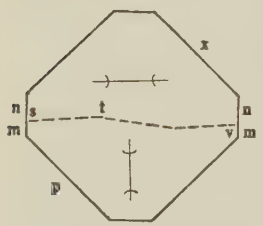


Fig. 6.—Bassetite: optical scheme of the crystal shown in fig. 4.

These data exclude the possibility of a rational twin-axis of low indices, even if rotation of 90° is admitted, and it must be assumed that the twin is a parallel growth of the axis a with the axis c of the second crystal.[1]

The following measurements were made between the principal zones by means of the two-circle goniometer:—

Zones.	Observed.	Calculated.
$[\underline{m}_1'''\underline{b}'m_1'']:[n_1''b']$	1° 27′	1° 26′
$[\underline{n}_1'''\underline{b}'\underline{b}'m_1'']:[\underline{m}_1'''\underline{b}'m_1'']$	89 22	89 17
$[\underline{n}_1'''\underline{b}'b'm_1'']:[n_1''b']$	89 11	89 17
$[\underline{n}_1'''\underline{b}'b'm_1'']:[\underline{b}'\underline{x}']$	45 14	45 13
$[\underline{n}_1'''\underline{b}'b'm_1'']:[\underline{b}'\underline{p}_2']$	44 42	44 47

Also, for the angle $x':\underline{x}'$ — Observed value, 89° 26′; calculated, 89° 17′.

Combination-planes.—The trace of the junction between the two crystals is clearly visible on the faces n_1'' and $\underline{m}_1'''$, where it is shown as a broken line in the drawing. The face $\underline{m}_1'''$ of one crystal is brought against the face n_1'' of the other and they meet in a slight angle. The line is stepped, being alternately parallel to the edge $\underline{p}_2\ \underline{m}_1'''$ and parallel to b. This suggests two combination-planes, b and m–$\underline{n}$, for both these pairs of faces are approximately parallel.

Examination between crossed nicols permits the direction of the trace of the combination-plane to be determined as it crosses the face b. The view that m–$\underline{n}$ is a combination-plane at once leads to the expectation that the trace of the boundary will be a straight line parallel to the edges bm_2'' and $\underline{b}\underline{n}_1'''$; examination in polarized light shows that, on the contrary, the compensation band follows the line stv (text-fig. 6), which

[1] Examples of similar twins are given by O. Mügge, Fortschritte der Min., 1911, vol. i, p. 42.

is incommensurable and inclined to the edge *bm* in the same way as the similar lines in the twin of specimen 2 (text-fig. 3). The angle between the edge *bm* and *st* was measured as 85° 40′, a value which agrees fairly closely with the approximate mean value 85° 19′ observed in specimen 2.

The general character of this combination plane recalls the ' rhombic section ' in the felspar group. The parameters *c* and *a* differ slightly in value, and a closer fit between the two sides of the combination-plane may therefore be obtained by selecting an irrational line in the face *b* inclined to the axis *a* of one crystal (*c* of the other) so that the distance between successive molecules along that line is the same in both crystals.

With reference to the pericline twin of felspar, Evans remarks[1]: 'The intergrowth accordingly takes place in such a manner that the edges of the plane nets of molecules giving rise to the brachypinakoidal cleavage, which outcrop from the two component structures on the plane of composition, exactly coincide.' In the present case the outcrop of the *c* cleavage is brought into coincidence with that of the *a* cleavage of the second member. If θ is the angle (measured in the same direction as the extinction) between the trace of the combination-plane and the *c*-axis of the crystal, and β' is the difference between β and 90°, then

$$\tan\theta = \frac{a-c}{a+c}\cot\beta'.$$

For the parameters given above, $\beta' = 43'$, $a-c = 0{\cdot}0017$, $a+c = 0{\cdot}6929$. The value of θ is then 11° 19′. The value actually measured is about 5°, but the position of the section is so sensitive that this value would be obtained from the formula if the angle *bn* (= 70° 56′), which is assigned to the crystal above, were diminished to 70° 53′; the latter value is almost equally consistent with the readings, and it may be recalled that Des Cloizeaux gives the value 70° 54′.

Chemical composition.—In 1875 Church (7) published analyses of the minerals from Cornwall and from Autun. He describes the former in the following words: ' The Cornish specimen occurred in thin isolated rhombic tables, translucent to sub-transparent, and was sulphur-yellow.' He concluded that the composition of the two was the same. In the absence of further description of the material it is difficult to be sure what mineral was analysed, and it is by no means certain that these, the only accurate analyses which appear to have been published for the Cornish material, were made on the mineral at present under discussion.

The mineral here described undoubtedly represents the Cornish

[1] J. W. Evans, Mineralogical Magazine, 1911, vol. xv, p. 393.

species, which was universally regarded as calcium uranyl phosphate. Although it belongs to the oblique system, the crystal measurements are so remarkably close to those of torbernite that it can be regarded with almost complete certainty as the isomorphous calcium salt, with the formula $Ca(UO_2)_2(PO_4)_2 \cdot x\,H_2O$, where x is probably eight.

Mineral *B* (Uranospathite).

Specimen No. 4.[1]

This specimen, from Redruth, shows fan-like groups of crystals in black gossan, composed of thin yellow rectangular plates (Plate VIII, fig. 3), which superficially have some resemblance to those from specimen no. 1. Closer examination reveals, however, important differences; they are strongly striated parallel with the elongation, and often exhibit curious rows of peg-like inclusions which originate on a line parallel with the end of the crystal and are prolonged parallel with the sides in the direction of growth (see Plate VIII, fig. 5). The extinction is sensibly straight, and measurements with the microscope show that the angle between the edges cannot be distinguished from 90°. The crystals will therefore be treated as rhombic, the plane of perfect cleavage being taken as *c*.

The development is symmetrical and pseudo-tetragonal, the corners of the plates being often modified equally by edges approximately at 45°. The crystals have the appearance of having been re-dissolved, and the edges are rounded; no goniometric measurements could be obtained, and the length of the axis *c* is therefore unknown.

Rhombic, $a : b : c = 1{\cdot}0 : 1{\cdot}0 : ?$

Cleavages: *c* perfect, *a* good, *b* (parallel with elongation) fibrous.

Specific gravity, by flotation, 2·50.

Optical properties.—The axial angle is wide, and the axial plane is parallel with the elongation, the negative acute bisectrix being normal to the perfect cleavage. The mean refractive index is somewhat below that of Canada balsam, a property which offers a ready means of recognizing the mineral in the slide (Plate VIII, fig. 1).

By immersion (Becke method), for sodium-light, $\beta = 1{\cdot}510$ and $\gamma = 1{\cdot}521$. The axial angle for sodium-light was found to be $2V = 69°$. The pleochroism is similar to that of bassetite, namely, $\beta = \gamma$ deep yellow, *a* pale yellow.

[1] No. L 1941, Museum of Practical Geology (Ludlam Collection).

Twinning is evidenced by the arrangement of groups of laths intersecting at right angles in the form of a cross, but the superposition of crystals at right angles is not common.

Chemical composition.—The remarkably low refractive index and specific gravity of this mineral at once distinguish it from the others here mentioned. Unfortunately, the material is so rare that it seems impossible to obtain sufficient for an analysis, nevertheless the physical properties afford some clue to its nature. The characteristic absorption-spectrum indicates that it is a uranyl compound, and this, coupled with the pseudo-tetragonal symmetry, suggests affinity with the uranite group. That it is a hydrated salt is evident from the behaviour in the desiccator, which recalls that of the Autun material.

Parallel Growths of Minerals of the Uranite Group.

Parallel growths of zeunerite on trögerite are described by Goldschmidt (11); according to Gaubert (13) small crystals of barium chloride orientate themselves as they form upon flakes of torbernite. In the examination of the present material, two extremely well-defined cases of this kind were encountered; with our present knowledge of the uranite group it would be early to attempt to trace their significance, but they may perhaps be briefly recorded.

Bassetite on Torbernite from Redruth.[1]

Gossan in which the cavities have been coated with torbernite of the stout habit usually found in the Redruth specimens; on this is a layer of honey-yellow crystalline bassetite, which in places has a definite orientation with respect to the underlying crystals (text-fig. 7), while in other parts independent crystals are found of a stout lozenge-shaped habit. Under the microscope, the bassetite is seen to be built up of a series of lamellae in twin orientation, and the faces of zones *m* and *n* which bound the lozenge are in consequence heavily striated and irregular.

The top of a composite crystal is shown in text-fig. 7. The torbernite yielded measurements which identified the forms {001}, {111}, {101}. On the base the layer of bassetite is relatively thin, while it is doubtful whether any has been deposited on the {101} faces; the growth is evidently determined by the {111} faces of the torbernite, and possibly by the base. The face of contact between the two minerals is turbid,

[1] Specimen No. L 1901, Museum of Practical Geology (Ludlam Collection).

with numerous small cracks which probably represent an initial stage in which the torbernite was attacked by the calcium-bearing solution. In another, somewhat similar, specimen, considerable replacement of the torbernite has preceded the growth of the bassetite.

Bassetite on Uranospathite.[1]

A group detached from this specimen consists of a crystal of bassetite attached to a lath of uranospathite, so that the axial planes of the two are approximately parallel (text-fig. 8, and Plate VIII, figs. 1 and 2), the somewhat elongated *c*-axis edge of the bassetite being parallel with the striations of the uranospathite, while the two crystals are joined on the plane of perfect cleavage.

In both the above cases, as in those described by other observers, the cleavages of the minerals lie in parallel orientation.

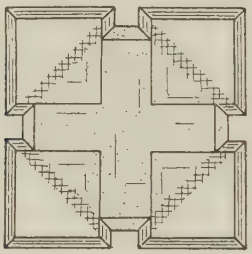


Fig. 7.—Parallel growth of Bassetite and Torbernite.

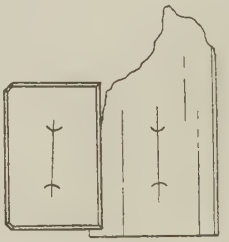


Fig. 8.—Parallel growth of Bassetite and Uranospathite.

Relationship between the foregoing Minerals.

The points of similarity between the substance *A* from Cornwall and that from Autun are no less remarkable than their differences. Both minerals are optically biaxial, negative, and possess about the same refractive indices, yet the axial angle in the Autun material is considerably the smaller. For the Autun mineral $\beta = 1{\cdot}575$ and $\gamma = 1{\cdot}577$ (Lévy and Lacroix, 9), whilst for the Cornish material $\beta = 1{\cdot}574$ and $\gamma = 1{\cdot}580$. Again, the densities of both, though somewhat variable, are indistinguishable, for the minerals float together in the same region of a density column, at a value of 3·10. Thus far the observations seem to favour the theory that the low angle of the Autun material is due to twinning. If the crystals are built up, according to the law

[1] Specimen No. L 1946, Museum of Practical Geology (Ludlam Collection).

described above, of lamellae oriented so that the a-axis is parallel with the c-axis, the optic axial angle would be reduced almost to zero, since the axial planes in this orientation lie at an angle of 89°; if, on the other hand, the twinning takes place by rotation about the axes c or a, or about the normal to (101) or (10$\bar{1}$), the angle between the axial planes is approximately either 8° or 74°. The axial angle derived from the first arrangement would seem to be too high, while the second would give rise to an axial plane bisecting the angle between the a and c cleavages. In the Autun material the plane is undoubtedly parallel to the cleavages, though an additional cleavage at 45° is occasionally to be observed.

Again, when the two minerals are placed over calcium chloride in the desiccator, it is found that the optic axial angle of the Autun material becomes zero; that of the Cornish crystals, on the other hand, remains high, whilst the extinction increases to about 20°, and the plates break up into four sectors with axial planes at right angles. The full description of the effects observed would be out of place here, but it is clear that the behaviour of the Autun material accords with rhombic symmetry, while that of the other is decidedly oblique. Such evidence, however, might still be explained as the result of sub-microscopic twinning, though the intimate and uniform structure required would be little different from that usually attributed to a crystal of higher symmetry.

Examination of the absorption-spectra of the minerals fortunately affords decisive evidence of their structural difference. If the two minerals are placed side by side opposite the slit of the micro-spectroscope it is at once evident that the system of five bands associated with the presence of the uranyl group is situated about 50 Angström units nearer the red in the spectrum of the Autun mineral, the difference being comparable with that of 10 Angström units observed by Rinne (12) between the spectra of torbernite and autunite. Here again, it is sufficient for the present purpose to remark that the difference exists; whatever its explanation, it is common to all good specimens of the two minerals, and it seems therefore impossible to include them in one species without extending the hypothesis of twinning to include an intimate molecular structure which, taken by itself, would be accepted readily as that of a rhombic crystal.

It seems clear, therefore, that no less than three distinct crystalline substances have been included under the name autunite; of these the Autun material has the best claim to the name, if only on the ground

that the word is derived from the type locality, Autun. It is unfortunate that the crystallographic data of the substance *A* should have been so closely identified with autunite, an error which is no doubt due to the rarity of the material. Although the chemical composition of the three minerals is possibly alike, apart from the water of crystallization, it does not seem possible to include them in one species as varieties of calco-uranite, for hydrates which differ crystallographically have hitherto been classed under separate names, in the groups with which they are isomorphous; the following names are therefore suggested for the substances classed under the headings *A* and *B* above :—

A.—*Bassetite*, after the Basset group of mines, one of the oldest and best localities for the mineral in Cornwall. Hydrated calcium uranyl phosphate. Oblique, $a : b : c = 0{\cdot}3473 : 1 : 0{\cdot}3456$; $\beta = 89° 17'$. Twinned by parallel growth of a and c axes so that the faces b are parallel, whilst the axis a of one individual is parallel to the axis c of the other. Cleavage, b perfect, also a and c. $G = 3{\cdot}10$. Yellow, transparent. Optical properties: Biaxial, $2E = 110°$ (Des Cloizeaux). Negative, acute bisectrix normal to b. Axial plane within the acute angle between a and c, inclined 4° behind the c-axis. $\beta = 1{\cdot}574$, $\gamma = 1{\cdot}580$. Pleochroic, $\beta = \gamma$ deep yellow, a pale yellow. Soluble in acids. In the desiccator the extinction-angle increases to about 20°.

B.—*Uranospathite*, in allusion [1] to the elongated tabular habit of the typical specimens. A hydrated uranyl salt. Rhombic, pseudo-tetragonal, $a : b : c = 1{\cdot}0 : 1{\cdot}0 : ?$. In elongated tabular crystals. Twin-axis perpendicular to (110), in cruciform groups. Cleavage, c perfect, a good, b ? fibrous. $G = 2{\cdot}50$. Yellow to pale green. Optical properties: Biaxial, $2V = 69°$. Negative acute bisectrix normal to c. Axial plane parallel to the elongation and to the fibrous cleavage. $\gamma = 1{\cdot}521$, $\beta = 1{\cdot}510$. Pleochroic, $\beta = \gamma$ deep yellow, a pale yellow. Soluble in acids. Becomes uniaxial in the desiccator.

The name autunite is retained for the Autun mineral, of which a comprehensive and detailed description has recently been published by Lacroix (14).

[1] From uranium and $\sigma\pi\acute{\alpha}\theta\eta$, a broad blade.

Literature.

The following list contains the papers to which reference is made in the text. In addition to these there are many notes reporting occurrences of the mineral, but it has not been thought advisable to attempt to collect them here.

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Explanation of Plate VIII.

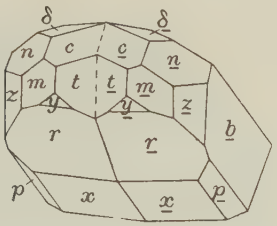
Fig. 1.—Bassetite (in relief) in parallel growth on uranospathite, mounted in Canada balsam. ×19.

Fig. 2.—The same, between crossed nicols. ×19.

Fig. 3.—Uranospathite as transparent tabular crystals, in the cavities of black gossan. ×4.

Fig. 4.—A 'chessboard' group of twinned crystals of bassetite (on the left) mounted by the side of a typical flake of autunite. The latter is also twinned, the composition plane being visible as a black diagonal line. Crossed nicols. ×19.

Fig. 5.—Uranospathite, a small terminated crystal. Crossed nicols. ×33.



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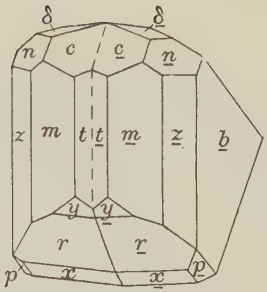

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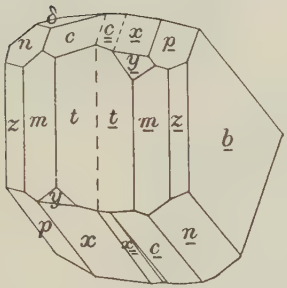

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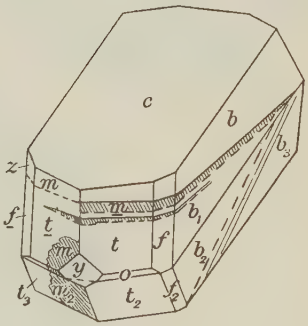

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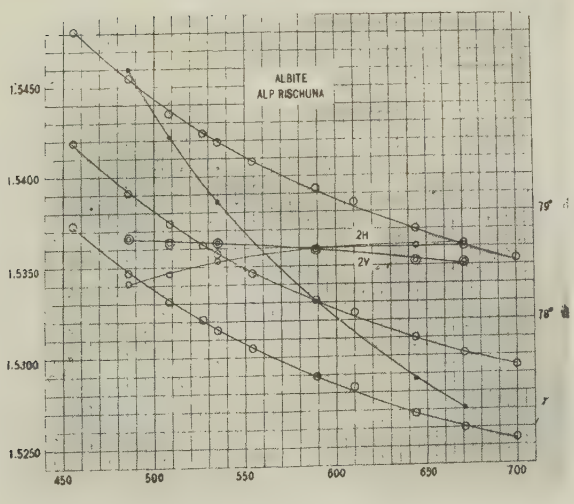

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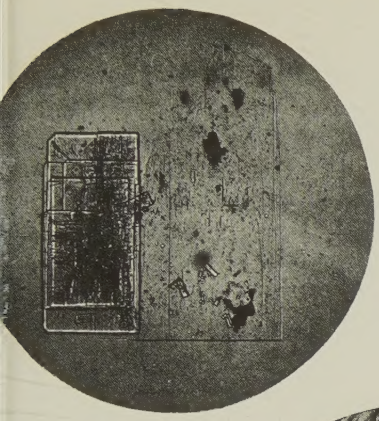
W. J. Lewis (and S. Kôzu): Albite from Switzerland.



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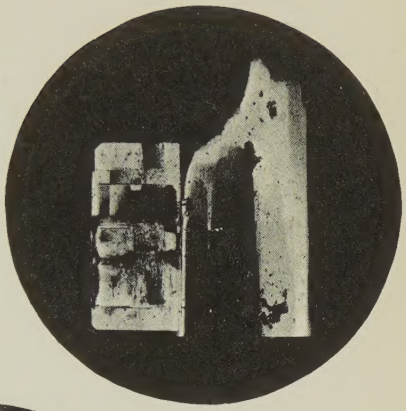

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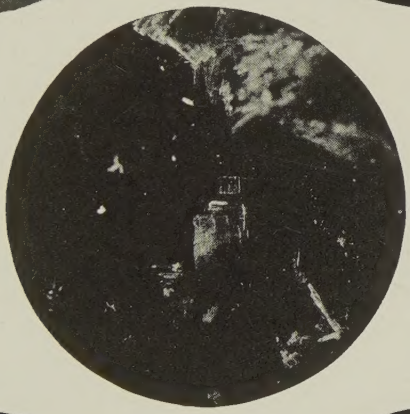

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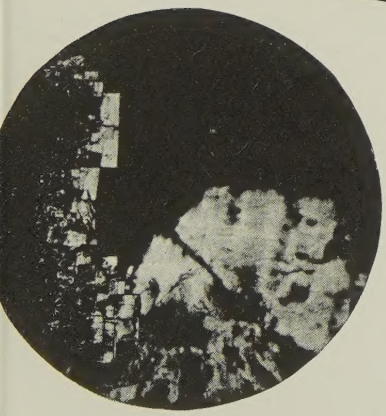

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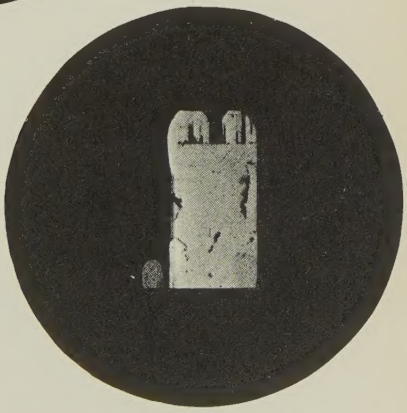

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